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A NEW METHOD FOR ESTIMATING CURRENT AND FUTURE TRANSPORT AIRCRAFT OPERATING ECONOMICS

AMERICAN AIRLINES, INC. MAINTENANCE AND ENGINEERING CENTER
TULSA, OK

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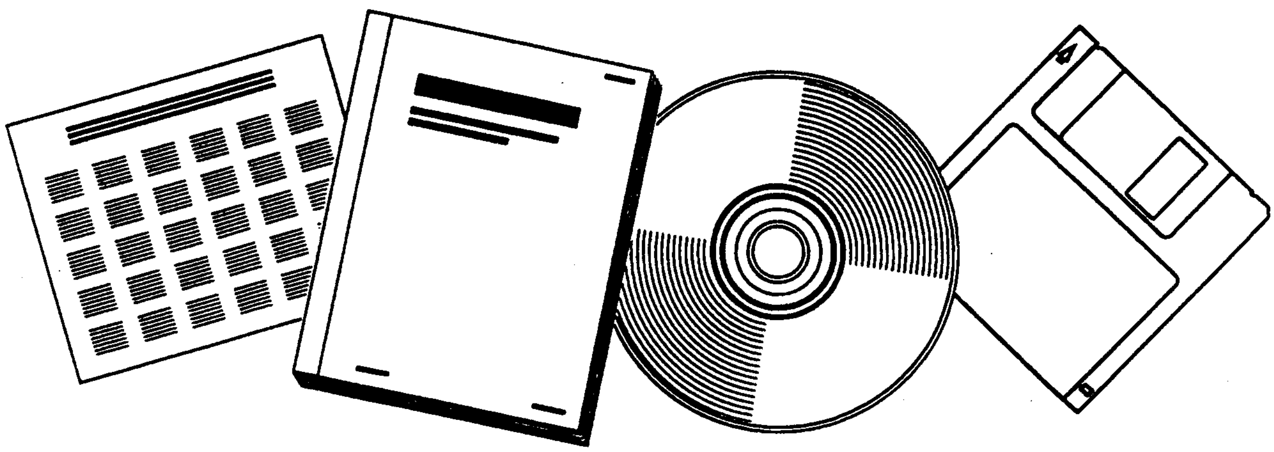

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16. Abstract
A methodology has been developed by which the operating cost associated with variations in aircraft design and technology characteristics can be assessed. This methodology addresses aircraft related operating cost elements and is based on an in-depth examination of American Airlines operating experience and relevant operating data collected by The Boeing Company from its customers.

The assessment method produces a base line estimate of the operating cost elements relating to such design specification features as seat capacity, avionic equipment, design range, and design definition features such as maximum takeoff gross weight, and number of engines. Means for determining the deviations from this base line of the design or technological difference at the specific ATA System level are provided.

The methodology has been applied to assess the operating cost of one potential future advanced technology transport aircraft. An analysis has been included to show the relative sensitivity of the operating cost to design parameters.

Areas of potential future research on operating cost related technologies are identified.

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1.0 SUMMARY

This study resulted in the development of an analytical model which relates subsonic commercial jet transport aircraft operating costs to the design characteristics and provides the means to assess the effects of alternative design approaches, the application of advanced technology and changes in airline operations. The methodology is adaptable to variations in the level of detail in the airplane design definitions so that it can be used to provide operating cost assessments in support of conceptual design studies or provide the basis for assessing alternatives to operational aircraft.

As an example, the developed methodology was used to assess the relative operating cost of an advanced technology transport design. This application served to illustrate the implications of the study findings and the areas where operating costs are likely to be affected by changes in design or technology.

A comparison of the total aircraft related operating cost of the Boeing Terminal Area Compatible Aircraft (TAC/Energy) and a conventional wide body aircraft (CWB-E) described in NASA CR 132608, *Fuel Conservation Possibilities for Terminal Area Compatible Aircraft*, is shown in table 1 and figure 1 for a standard stage length. A comparison of the airframe Direct Maintenance Cost (DMC) of these two aircraft by system group is shown in figure 2. Figure 3 shows a comparison of direct airframe maintenance costs as assessed by the new method, by the 1967 Air Transport Association of America (ATA) method, and by an aircraft manufacturer's ATA method updated to include recent operational experience.

Table 1.—Operating Cost Comparison—TAC/Energy and CWB-E Cost Per 1852 km (1000 nmi) Flight, 1976 Dollars/Flight

	TAC/Energy	CWB-E
Fuel	759.45	1068.70
Maintenance		
Airframe	249.99	252.86
Propulsion system	296.05	296.45
Burden	509.80	502.14
Flight crew pay	569.80	613.41
Flight attendant pay	309.20	313.32
Aircraft servicing		
Direct	62.04	62.04
Burden (2.3 x labor)	141.33	141.33
Landing fees	151.80	195.44
Aircraft control fees (air ground communications)	7.00	7.00
Cash operating costs	3055.18	3452.69
Insurance	142.39	158.06
Depreciation	988.78	1096.96
Total	4186.35	4707.71
Flight length (hrs)	2.269	2.300
Trips/year	1235	1220

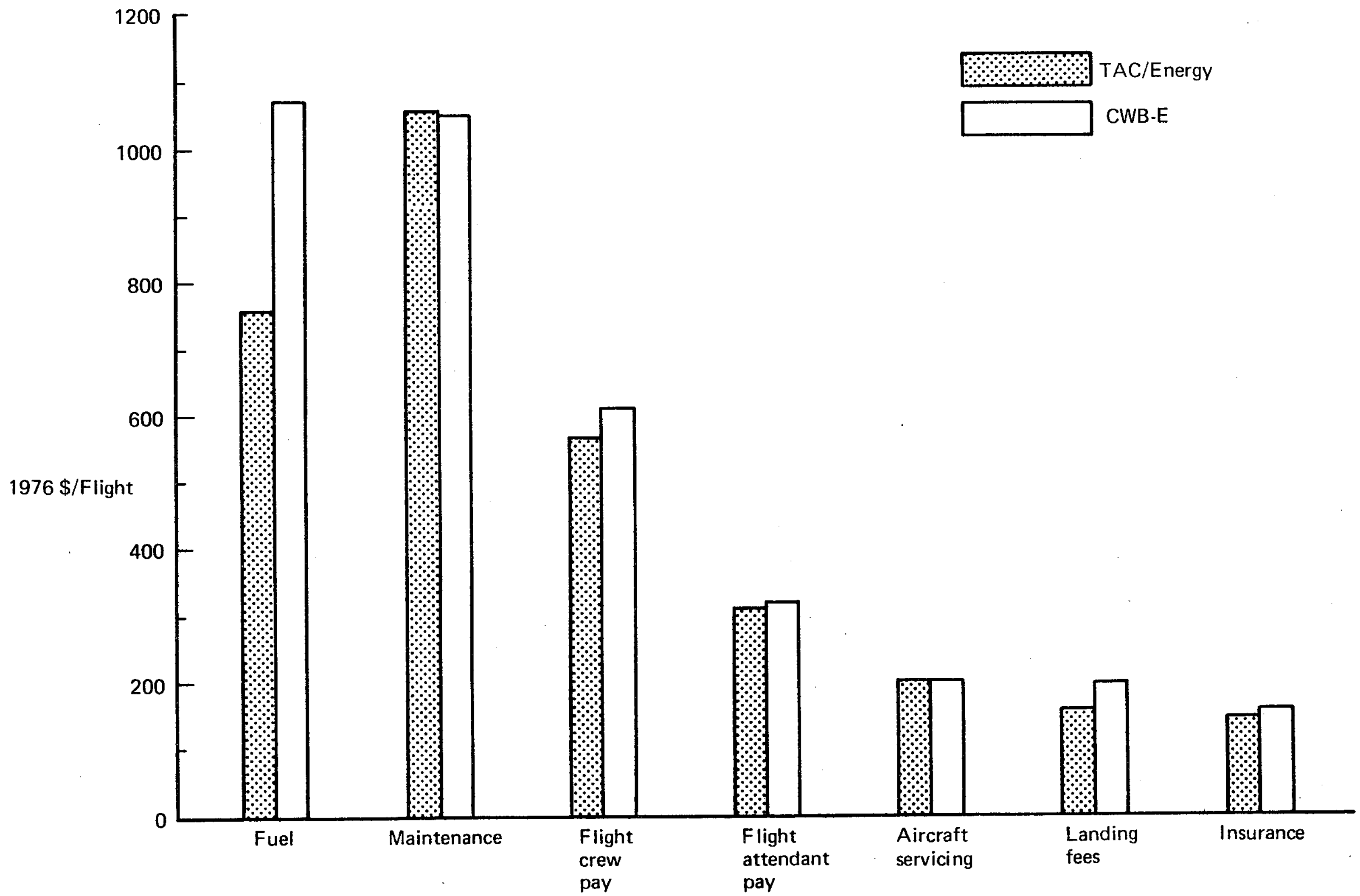

Figure 1.—Operating Cost Comparison

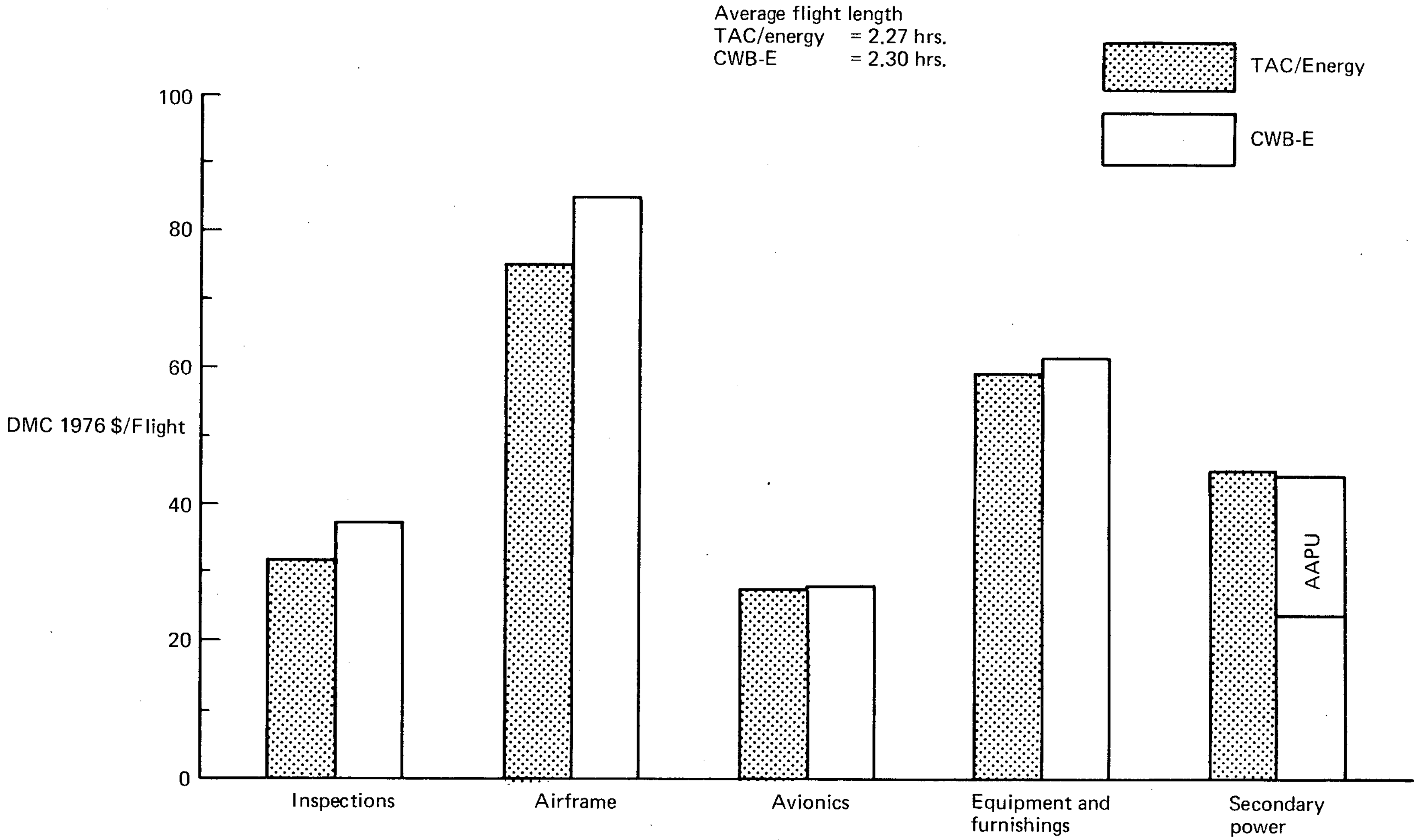

Figure 2.—Airframe Maintenance Cost Comparison

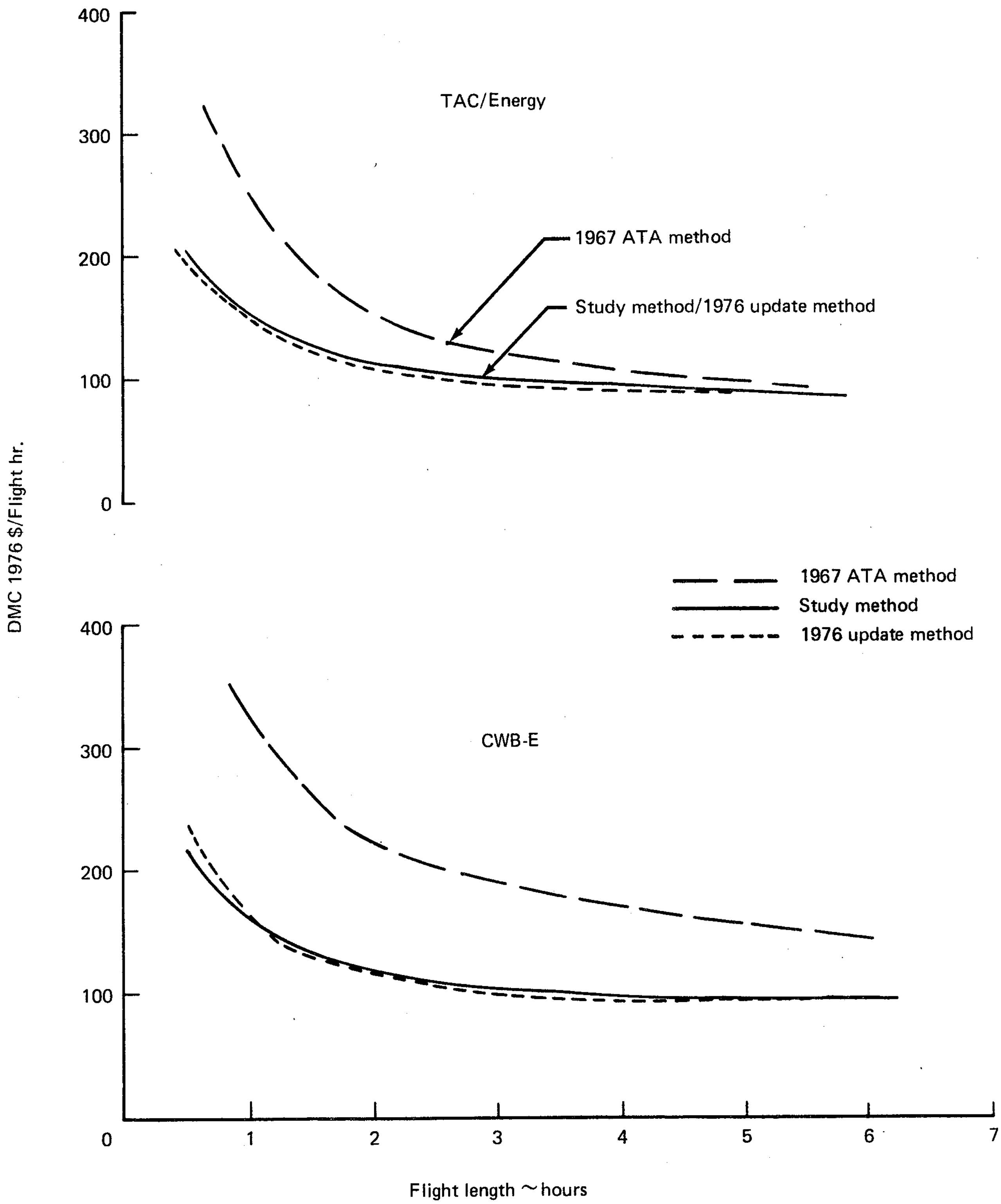

Figure 3.—Airframe Maintenance Method Comparison

The study method provides a better awareness of the probable effects of incorporating advanced technology and/or significant changes in design features than is available from the ATA methods, because the analysis is based upon technology related parameters. The new methodology should also be found to be more effective as a predictive tool since it is based on the cause-and-effect relationship between the expense elements and the design and technology features.

This method can help the preliminary design engineer to assess the probable operating costs of new design concepts. It will assist the project engineer by providing a means of including operating costs in trade studies. It will also assist the researchers in evaluating the needs and potential gains from research. And, it can provide the airline a framework with which to assess the plan for new equipment.

Application of this new methodology as a predictive tool must be made with due caution and respect for the empirical correlation techniques on which it is based. Particularly, these correlations should be reviewed and updated from time to time as additional experience is accumulated with current equipment and new equipment as it is introduced.

Areas for further research and development in operating cost related technologies brought to light by this examination of the costs of operating commercial aircraft, are discussed in detail in section 7.

The study resulted in the development of the following method for estimating airplane operating costs for domestic service.

The total airplane related operating costs may be stated as follows:
Operating costs (1976 \$/trip) =

Depreciation $= \dfrac{\text{Purchase price* − residual}}{\text{Depreciation period}} \times \dfrac{1}{N}$

\+ Insurance $= \dfrac{1\% \text{ of purchase price}^{\dagger}}{N}$

\+ Control fee = \$7.00 without data link or
= \$4.00 with data link

\+ Landing fee = \$1.54/1000 kg of landing weight

\+ Aircraft servicing

Narrow body = 0.02 x seats x \$9.50/man-hour (labor)
\+ 0.002 x seats (material)

or

Wide body = 0.033 x seats x \$9.50/man-hour (labor)
\+ 0.003 x seats (material)

\+ Flight attendant pay $= [0.691 \times FL + 0.00175 \times (FL)^2] \times \text{seats}$

\+ Flight crew pay** $= 174 \times FL + 43.5 + 0.452 \times FL + 0.11299) \times \dfrac{MGW}{1000} \text{ kg}$

---

*Including airframe and engine spares
**The expression given is for a 3 man crew—for a two man crew, use 75% of this value.
† Does not include airframe and engine spares.

+ Fuel expense $= \frac{\text{Liters}}{\text{Trip}} \times \frac{\text{Dollars}}{\text{Liter}}$

+ Maintenance cost See section 4.4.5

where FL = Flight length, hours

$$\text{Utilization} = N = \text{No. of departures per year} = \frac{3205}{FL + 0.327}$$

Note: To determine airplane related costs in other than 1976$, apply escalation factors determined by experience or from data published in the Metals and Metal Products section of the Wholesale Prices Index–Code 10 and the Gross Earnings of Production Workers in the Aircraft Industry–SIC372–Bureau of Labor.

2.0 INTRODUCTION

2.1 BACKGROUND

There has been a growing concern, particularly within the air transportation community, about the adequacy of methods for assessing the potential benefits to be gained from new technology and design innovations when applied to commercial transport aircraft.

The assessment of the potential benefits to be gained from new technology and design innovations depends upon the availability of a sound operational cost evaluation method. In such a method the operating cost impact of various design or technological alternatives could be evaluated using their known or predicted physical characteristics. When combined with the airplane performance and configuration features, this method would provide an assessment of the benefits to be gained from aeronautical research and development activities.

This cost assessment method should be responsive to variations in the design features, technologies and performance characteristics which determine the various operating cost elements. The method should recognize the interactions of specific technological approaches and design features with the overall airplane characteristics and performance in order to scope the combined impact on the operating cost elements.

In line with NASA's objectives of improving the usefulness, performance, safety and efficiency of aeronautical vehicles, and to augment NASA's ability to assess the potential benefits to be gained from technological advancements, NASA undertook a prior study, reported in reference 1. That study provided the perspective with which to guide and assess propulsion systems related operating costs. The present study was undertaken to develop a similar in-depth understanding of airframe related operating expenses and to combine this with the earlier propulsion study, thereby achieving a complete airplane operating cost methodology. In this context the airframe includes avionics, secondary power systems, payload related equipment and furnishings, as well as the airframe structural and flight functional systems.

2.2 STUDY OBJECTIVES

The primary objective of this study was to develop a method (analytical model) which would relate commercial aircraft operating cost elements to airplane design features and technological characteristics.

In order to be useful during the various stages of airplane design development, the methodology had to be adaptable to variations in the level of detail in the airplane design definition, and be responsive to alternative design features and the effects of incorporating advanced technology.

Further, it was the objective of the study to use the developed methodology to assess an advanced technology aircraft design for the purpose of illustrating the use of the methodology. The study would provide a perspective of the operating cost changes due to the advanced technology, and show the relative operating cost significance of selected design and technology advances, especially those used to reduce fuel consumption.

2.3 SCOPE

This investigation analyzed airplane operating cost historical records, manufacturer's data, together with engineering judgment to determine the impact of advanced technology on airframe and airframe systems' total operating cost. Aircraft related operating costs fall into several distinct areas as noted in figure 4. Depreciation expenses are those associated with the writeoff of the initial aircraft and engine purchase price, and their spares and related capitalized investments occurring after the airplane has been purchased—such as for airplane improvement programs. Insurance costs cover those costs normally falling into the category of hull and liability insurance. Crew pay is the cost associated with the cockpit crew pay and benefits which may be tied through contract to certain of the design and operating characteristics of the aircraft. Fuel costs are those associated with the cost of fuel to fly the mission including ground operation fuel usage. Maintenance costs are associated with maintaining the aircraft in a safe and efficient operating condition.

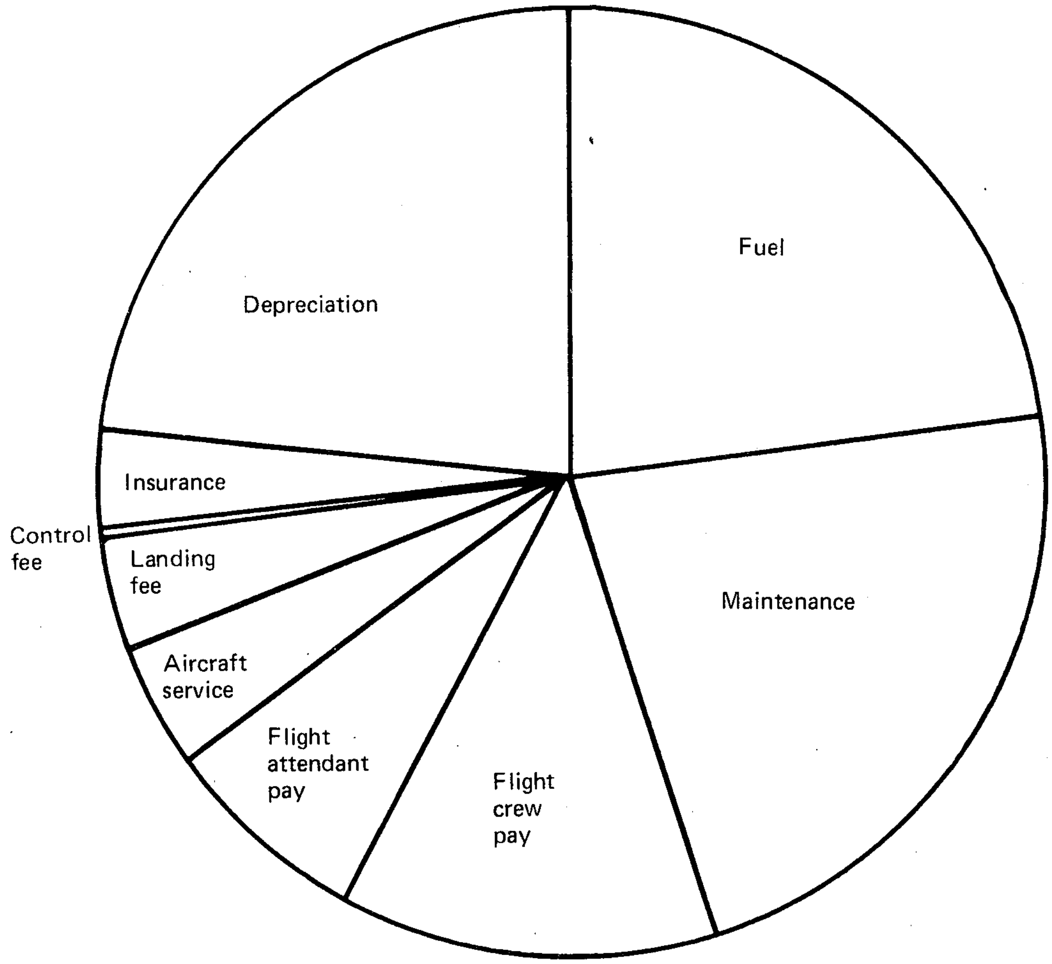

Figure 4.—Representative Distribution of Aircraft-Related Operating Expenses

These elements are affected by technology, although the degree of impact varies among them. In addition, there are costs normally categorized as *indirect* operating expenses that may also be affected by technology. These expenses encompass such things as aircraft control fees, aircraft servicing expense, facility costs, landing fees, ground equipment cost, and flight attendant expenses. Each category of operating costs described above was examined to determine the extent to which advanced technology had impacted the operating cost element and to identify the major technological opportunities for improvement.
The operating cost assessment methodology developed from analyses of the experience data base and correlations of the data with design, technology, and operational characteristics, was to be a systematic description of the relationship of the operating costs to design, technological, and operational features. The operating cost methodology so developed was to be used as a base or framework from which to estimate the probable effects of alternative design features, the incorporation of advanced technology, and/or changes in airline operations.

It should be understood the fairly widespread variations in airline cost accounting practice, plus changes and/or modifications to operating cost producing elements which occur from time to time, make it virtually impossible to develop a universal cost method which could yield precise, absolute costs. Accordingly, it was not the objective of the study to attempt to develop an absolute cost model, but instead, the method to be developed was intended to be usable for predicting *relative* costs, (i.e., comparisons between different aircraft with similar levels of technology) with sufficient accuracy to serve as a design guide and an indicator of relative aircraft operating costs. Nevertheless, in attaining this goal the intention was to achieve the most realistic operating cost levels possible through the use of the extensive historical realworld data bases compiled from American Airlines and The Boeing Company records.

2.4 GENERAL STUDY APPROACH

The general approach to the study was to obtain a statistically significant data base of the operating cost experience of American Airlines' fleet of Boeing B707, B727, and B747 aircraft, and its McDonnell-Douglas DC-10 aircraft. In addition, the Boeing Service Experience Retention Files, encompassing industry-wide data, were used to supplement the American Airlines experience data. These were also used to guide the correlations and analyses fundamental to the cost assessment method development, and to judge the representativeness of American Airlines' experience compared to the fleet in general.

Within the limits of the funding available for this investigation, the Aircraft Related Operating Assessment Method has modeled direct and aircraft related indirect operating costs identified earlier, and it has, in particular, modeled operating expenses down to the ATA system level for maintenance expense.

The Propulsion Systems assessment method needed to complete the total airplane operating cost assessment was obtained from application of the method of reference 1, adjusted to a consistent format including same-year costs. Further analysis of the Propulsion System costs were excluded from this study.

The incorporation of alternative design approaches, advanced technology, and/or different operational practices could affect operating expenses by introducing changes in scale (gross weight, seat capacity, etc.), performance (speed, fuel consumption), reliability (mean time between repair), repairability (expense per repair), flight length per departure and/or equipment utilization.

The approach used to develop this methodology was to identify the relevance of these factors and develop a base from which to logically account for changes. Identification of scale effects, performance effects, and operational effects account for the impact of the resulting changes in the overall design and mission characteristics. Changes in reliability and repairability effects account for the maintenance cost impact at the individual ATA system level.

3.0 ABBREVIATIONS AND SYMBOLS

AAL	American Airlines
APL	airplane
APU	auxiliary power unit
ATA	Air Transport Association of America
ATC	Air Traffic Control
ARINC	Aeronautical Radio Incorporated
BITE	build-in test equipment
BPR	bypass ratio
CAB	Civil Aeronautics Board
CG	center of gravity
DMC	direct maintenance cost
DCN	delays and cancellations
FC	flight cycle
FH	flight hour
FL	flight length
Hr	hour
INS	inertial navigation system
K	Kelvin
kgs	kilograms
km	kilometer
kts	knots
kVA	kilovolt amperes
LRU	line replaceable unit
M	mach number
MLW	maximum landing weight
MGW	maximum gross weight
N	utilization
NHA	next higher assembly
nmi	nautical mile
OEW	operating empty weight
PL	payload
POD NAC	podded nacelles
QEC	quick engine change unit
R	range
RF	range factor
RFI	radio frequency interference
R_s	stage length
SLST	sea level static thrust
TAS	true air speed
TOGW	takeoff gross weight
TSFC	thrust specific fuel consumption
V	cruise speed
W_f	block fuel
W_L	landing weight
W_R	reserve fuel
W_1	initial gross weight
W_2	final gross weight
$\frac{L}{D}$	lift drag ratio

4.0 OPERATIONAL COST ASSESSMENT METHODOLOGY

4.1 AMERICAN AIRLINES DATA

The following is a description of the utilization of the basic fleet operations statistics of American Airlines. Since many of the operating expense elements are periodic, it was important to the validity of the study to obtain statistical data from as long a sequential operating time period as practical. The data collected through daily operations of over 1000 aircraft flights a day is collected on computer tape files from which various groups within the organization extract summaries pertinent to their particular needs. These summaries are sometimes in the form of computer tapes and/or hard copy computer printouts. With respect to the needs of this particular investigation, some hard copy historical files were directly applicable, but in many cases the needed summations were unique, and it was necessary to go to the basic transaction tapes and develop new summary files. The gathering of statistically significant data in the form suitable for the correlations and analyses which follow was a major study task.

To be manageable, the operational expense data was summarized on seven passenger aircraft types and two dedicated freighter types. This provided a base upon which to run simultaneous correlations of up to nine independent variables. However, there were often particular data points that were believed not to be representative, for one reason or another, e.g., warranty provisions, or known errors (of uncertain magnitude) in the basic records. Further, some of the independent variables appeared to correlate with each other and could not be rationally separated by the simultaneous data correlation techniques.

In recognition of the above, the general technique adopted for this study was as follows. For each data correlation a model was hypothesized, the correlation analyzed and the hypothesis revised or accepted. The hypothesized models for maintenance expenses at the ATA systems level were based on the component to system relationship included in Appendices IV and V.

4.2 FLEET INVESTMENT EXPENSES

4.2.1 AIRCRAFT UTILIZATION

Aircraft utilization in hours per day, or hours per year, is commonly used as a normalizing parameter to relate the fixed operating expense items (e.g., depreciation, facility rentals) to the variable expense items (e.g., maintenance, fuel, crew pay). A survey was conducted to determine the actual utilization of the domestic trunk fleet. 1974 and 1975 CAB form 41 data was used which included some 1367 turbofan aircraft made up of 18 models flying about 6600 flights a day.

Examples of fleet utilization are shown in figure 5. The data is displayed as histograms of the average block hours per day for various equipment types for the total domestic fleet. The implication of these distributions is that the utilization is dependent upon the individual airlines route structure and passenger demand eccentricities rather than the technical characteristics of the airplane.

The following discussion is offered to establish representative fleet utilization values, and to examine the relationship of such average utilization to aircraft design and technological characteristics.

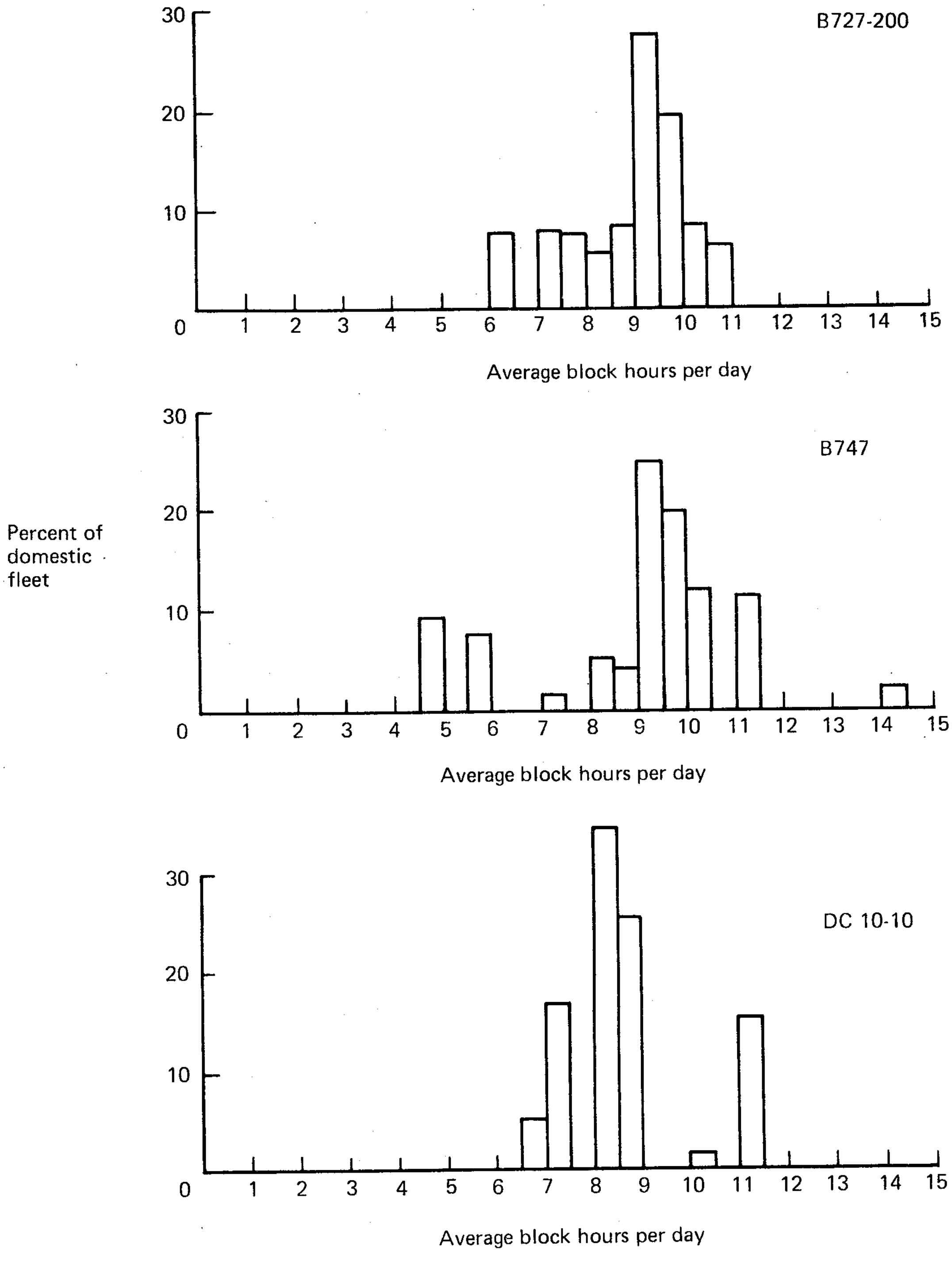

Figure 5.—Fleet Utilization Distributions

The average trip block time and flight times for the total domestic turbofan fleet correlate well with the stage length (figure 6), and can be represented by the following linear function of the stage length.

$$\text{Flight time} = 0.258 + .00117\ R_s\ (\text{km})$$
$$\text{or} = 0.258 + .00216\ R_s\ (\text{nmi})$$

$$\text{Block time} = 0.415 + 0.00125\ R_s\ (\text{km})$$
$$\text{or} = 0.415 + 0.00231\ R_s\ (\text{nmi})$$

where R_s = Stage length - km (nmi)

The difference between the block time and the flight time—taxi and runway time—apparently varies linearly with stage length, varying from about 11 minutes average for 371 km (200 nmi) stage lengths to 24 minutes average for 2900 km (1565 nmi) stage length with an overall fleet average of about 14 minutes. This is believed to be the result of the larger aircraft being operated from larger airports with longer runways, greater taxiing distances and greater separation distances.

As a basis for judging the sensitivity of utilization to design parameters, it was hypothesized that the number of trips per day was a function of the available operating hours and the time required for each trip. The available operating hours for which the airplane may be scheduled is considerably less than twenty four because of departure and arrival time constraints due to passenger demand, curfews, etc.

The time required per trip is a function of the block time and additional times associated with passenger loading, servicing, and maintenance which may in turn be related, in part, to block time or flight time.

Based on these assumptions, operational experience data on number of trips per day was regressed as a function of range as shown in figure 7. The resulting relationship was combined with the above block time equation to produce a relationship between utilization and block time.

The resulting relationships were used to develop curves of daily aircraft productivity in terms of flight hours/day, block hours/day and distance flown per day, figures 8, 9, and 10.

Figure 8 shows that the changes in block hours/day due to speed changes are negligible at the mean range shown in table 2. The increase in the average number of flights per day is offset by the reduction in average time per flight. Figure 9 shows the trend of flight hours per day and utilization (block hours/day). The average daily miles flown per day is shown in figure 10.

In light of the apparent dominance of block time (or flight time) as the determinant of trips per day or year, a regression of the operational experience data was made against flight time, figure 11.

Flight time was chosen as the input parameter as it appears to be a consistent generic determinant of a majority of the aircraft operating cost elements, and in the case of annual utilization appears to be the only significant parameter.

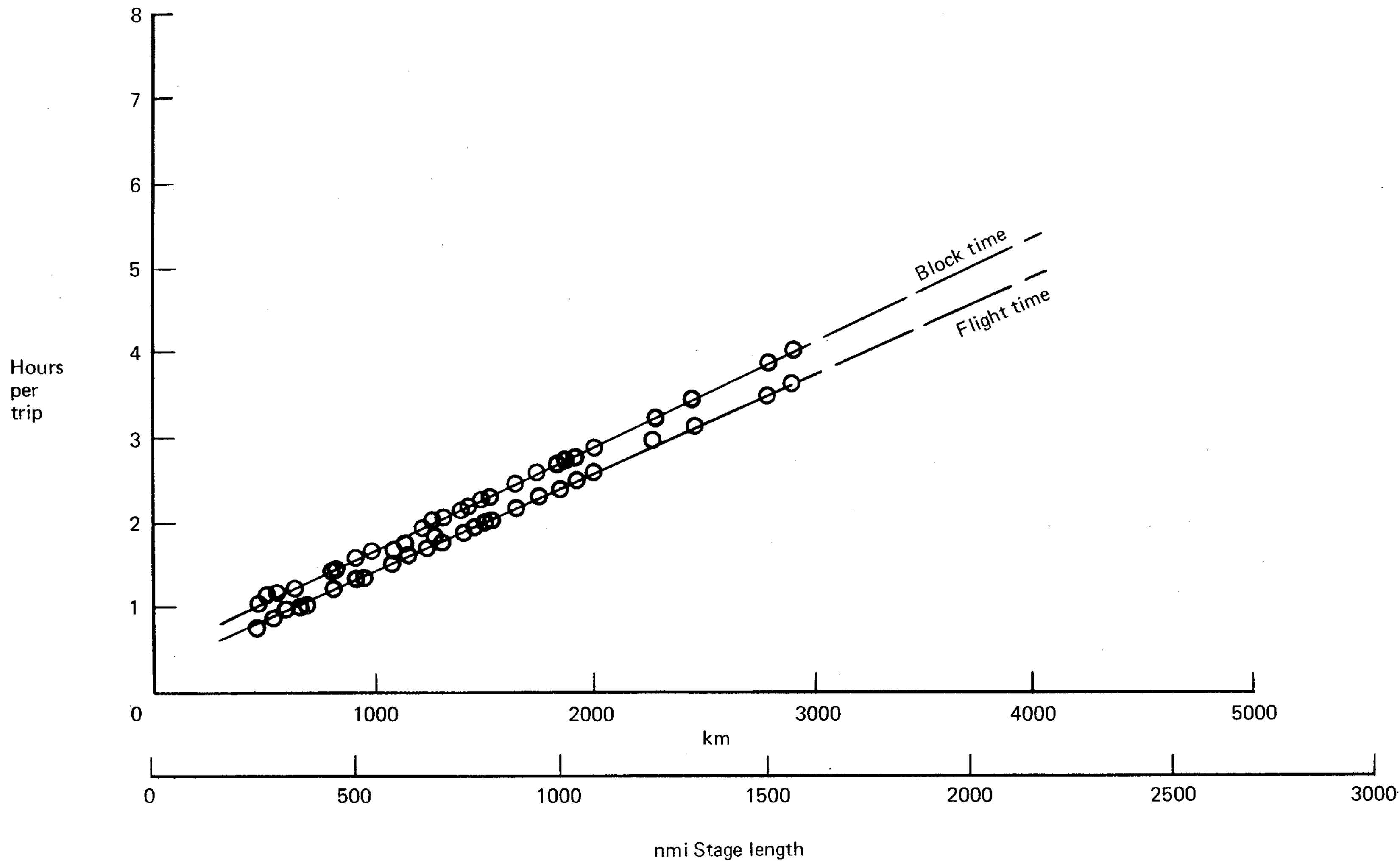

Figure 6.—Airline Fleet Trip Times

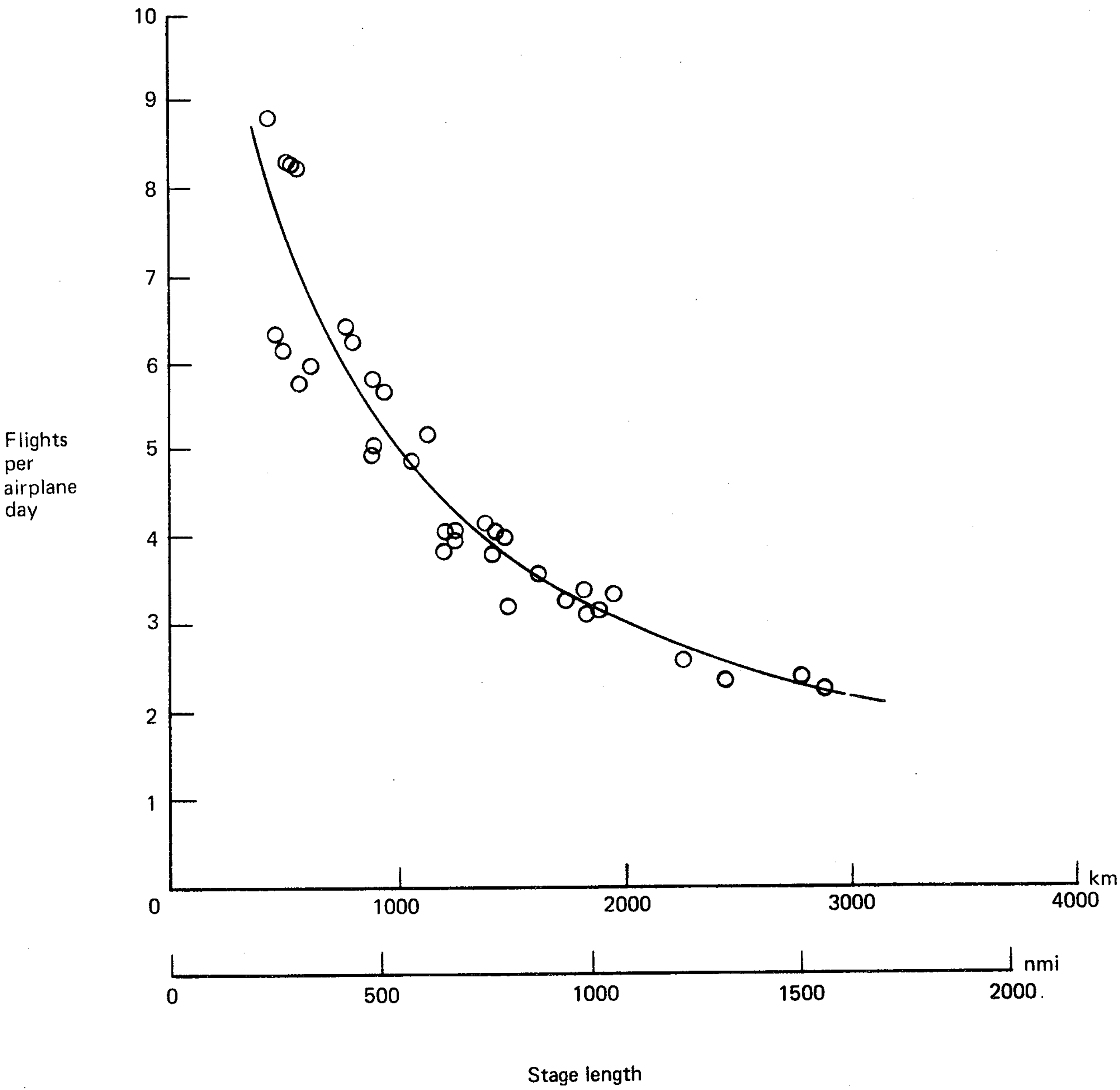

Figure 7.—Fleet Average Trips Per Day

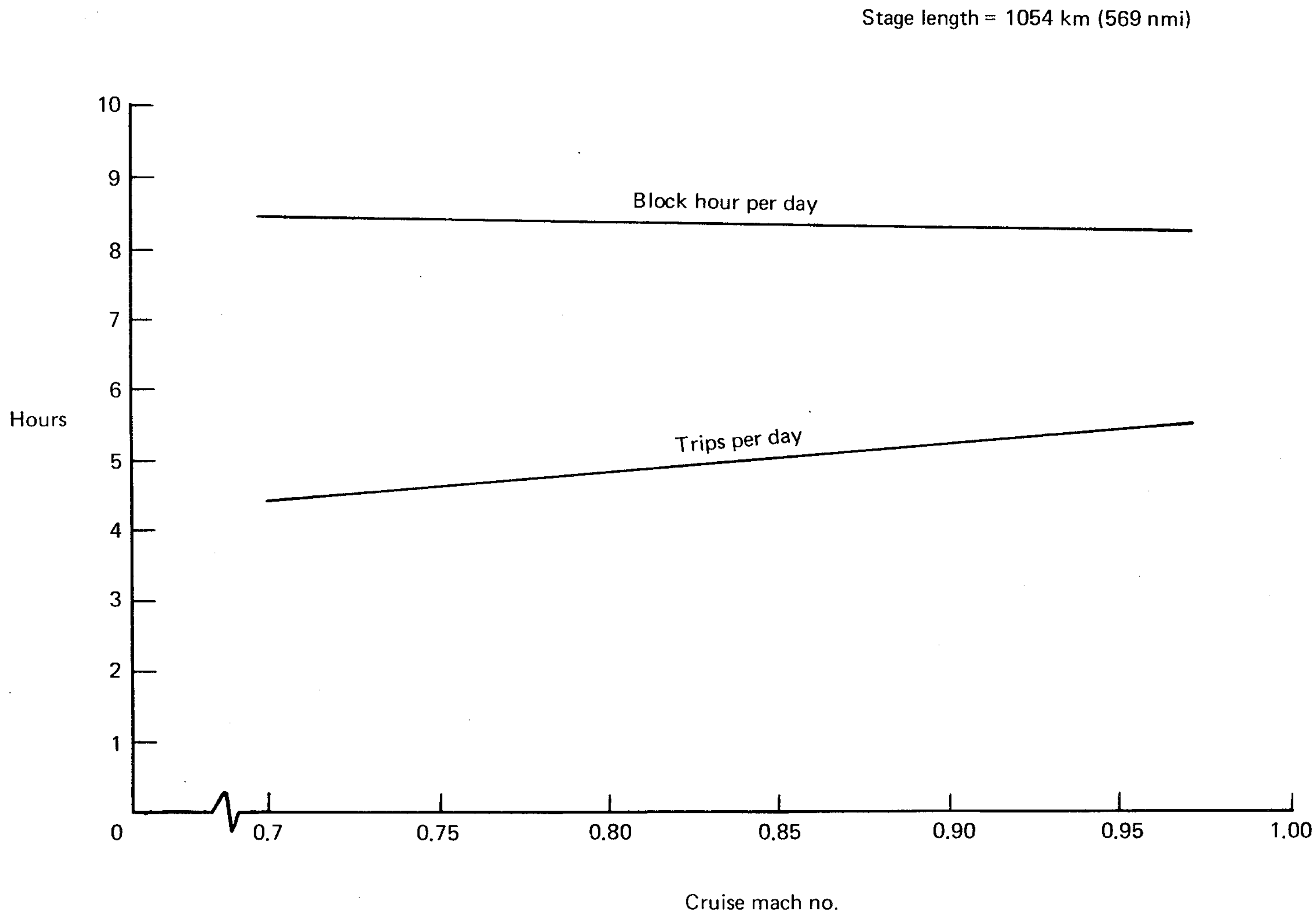

Figure 8.—Effect of Cruise Mach on Productivity

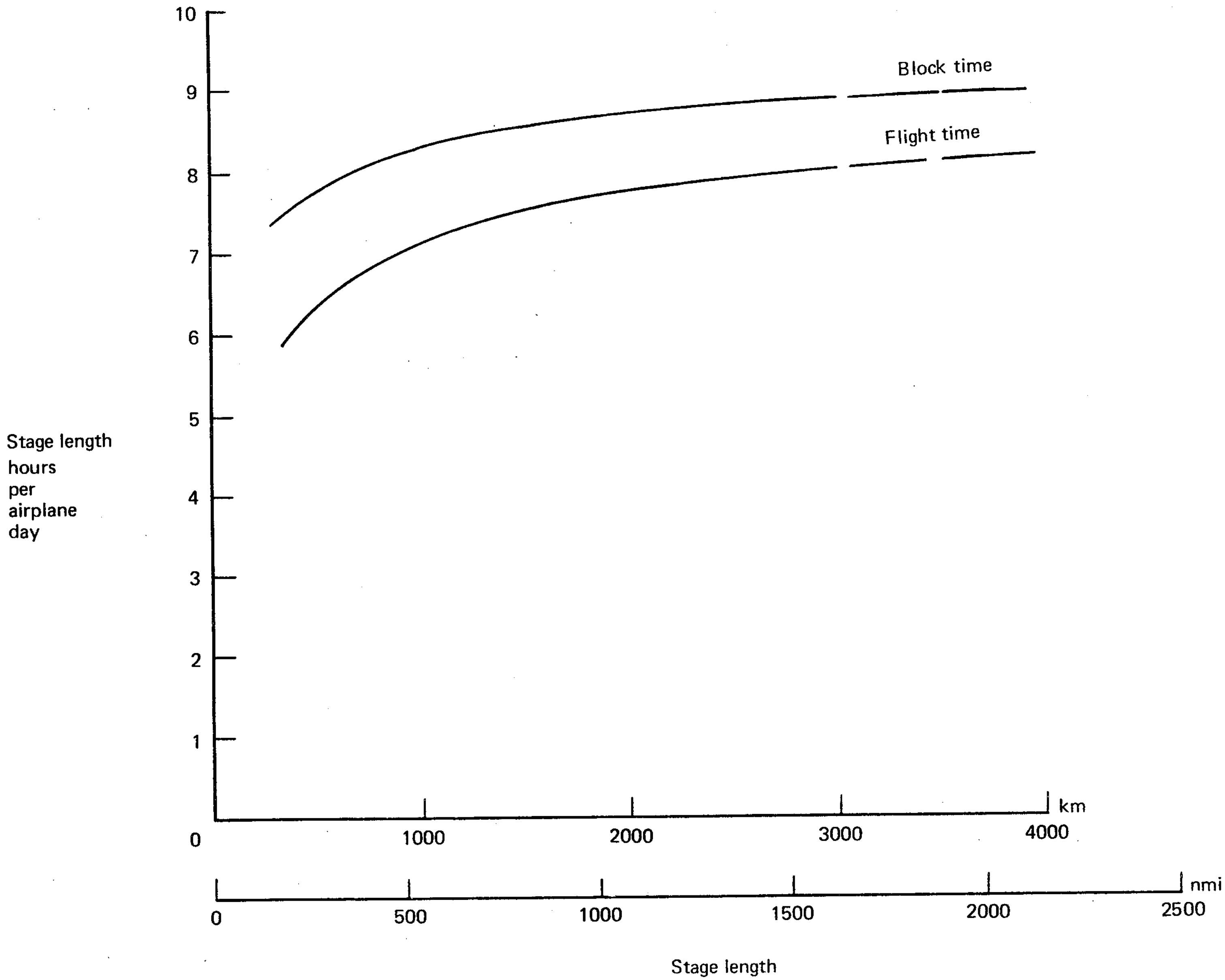

Figure 9.—Daily Utilization and Flight Hours

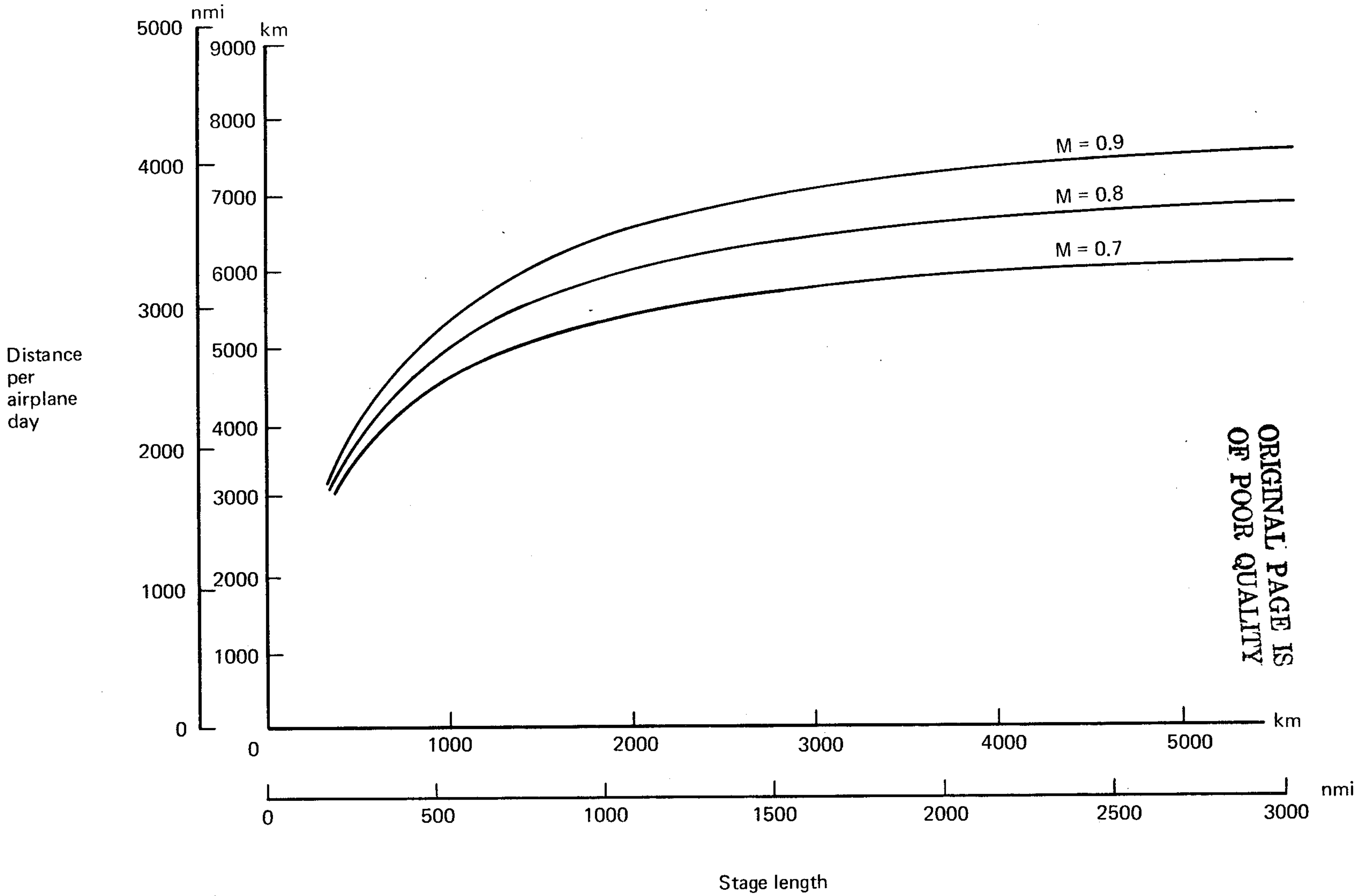

Figure 10.—Fleet Average Miles Per Day

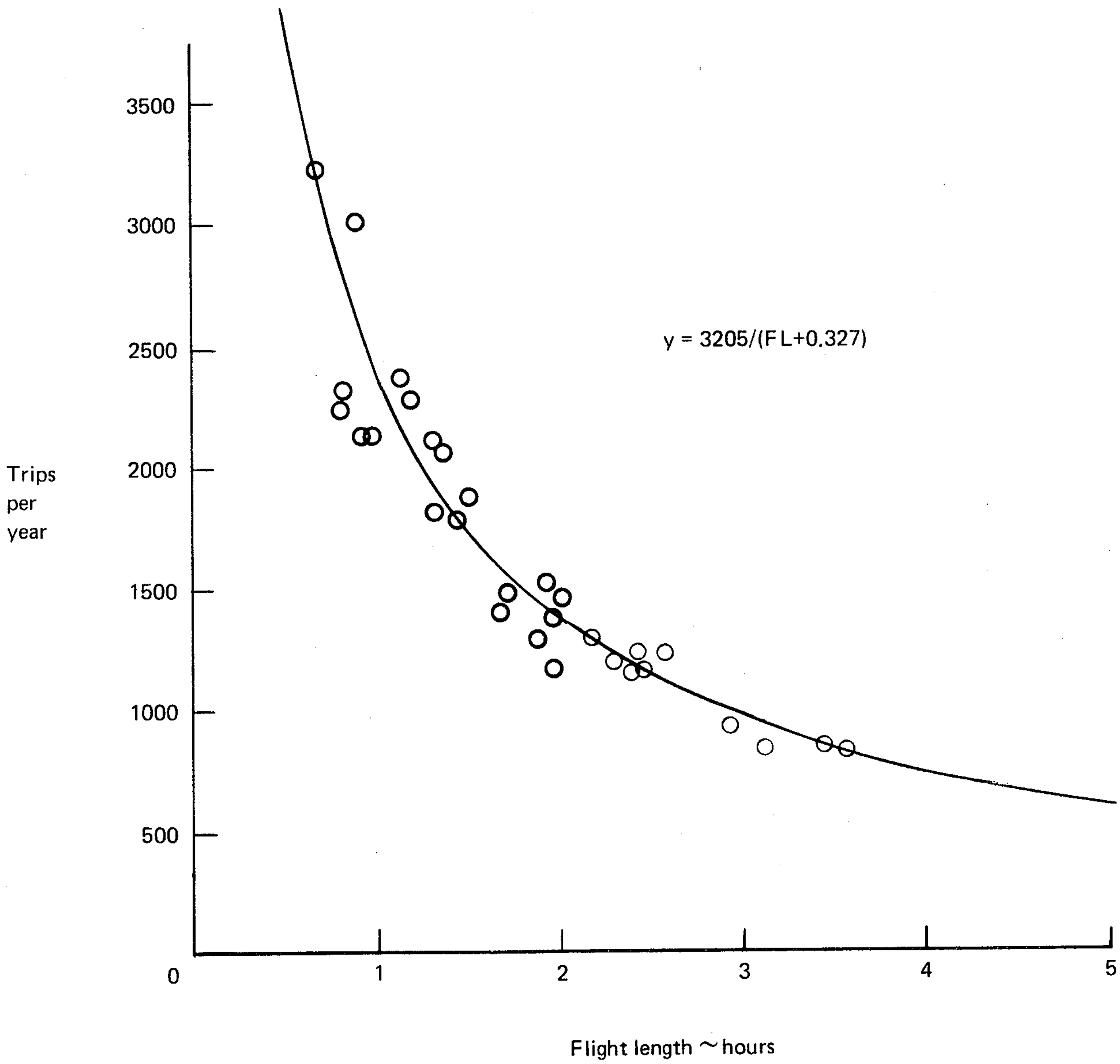

Figure 11.—Annual Utilization Model

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Table 2.—Total Fleet Average Utilization Factors

Mean values for domestic trunk turbofan fleet 1974 and 1975

Mean stage length	1054 km (569 nmi)
Mean flight time/cycle	1 hr 29 min
Mean block time/cycle	1 hr 43 min
Number of flights/day	4.84
Flying time/day	7 hr 12 min
Utilization (block time/day)	8 hr 21 min
Distance per day	5100 km (2752 nmi)
Block speed	614 km/hr (331 kts)

4.2.2 DEPRECIATION EXPENSE

As defined by the CAB: "Depreciation is the loss in the service value of depreciable property and equipment (in this instance, flight equipment), neither restored by current maintenance nor against which the carrier is protected by insurance. This loss must be incurred in the course of service by causes known to be in current operation, the effect of which can be forecast with reasonable accuracy. The causes of depreciation include wear and tear, decay, action of the elements, inadequacy, obsolescence in the art, changes in demand and the requirements of public authorities."

Depreciation of the capital value of an airplane is dependent to a large degree on the management philosophy of each individual airline, tax laws, world economic pressures and competitive conditions.

To provide some degree of uniformity in the establishment of a depreciation schedule, the Civil Aeronautics Board has provided the guidelines for subsonic aircraft shown in table 3.

Table 3.—Civil Aeronautics Board Depreciation Guidelines

Aircraft type	Depreciation period	Residual
		% of initial purchase price
Turbo prop (twin engine)	10 years	15%
Turbo prop (four engines)	12 years	5%
Turbo jet powered (2, 3 or 4 engines)	10 years	5%
Turbo fan powered (2, 3 or 4 engines)	14 years	2%
Wide body aircraft	16 years	10%

Airlines are allowed to vary from these guidelines and American Airlines currently has filed the depreciation schedule of table 4 for its flight equipment with the CAB.

Table 4.—American Airlines' Depreciation Schedules

Aircraft type	Depreciation period	Residual
		% of initial purchase price*
707-123 aircraft (delivered 1959 through 1961)	Terminates 12/31/77	$100 000
707-123 and 323 series aircraft (delivered 1962 and on)	15 years	$100 000
727-023 and 223 series	16 years	10%
747 and DC10 aircraft	14 years	15%

*Note: The book value of an aircraft may be increased from time to time by the value (investment) of major modifications and/or improvements made to the equipment.

As evidenced, technology per se has no apparent direct effect on depreciation. There is an indirect effect, however, which is related to the influence of technological advances on flight equipment purchase price. As the flight equipment purchase price forms an ingredient of the operating cost methodology, the effects of technology and its subsequent effect on flight equipment depreciation expenses are reflected in the model.

As also evidenced in table 4, airline management philosophy and not aircraft design life determines the amount of deviation from the CAB depreciation guidelines. Hence, in order to provide a realistic input to the development of the operating cost methodology, the following representative depreciation schedule will be used to develop the form of the depreciation cost portion.

$$\text{Depreciation} = \frac{\text{Purchase price}-\text{residual}}{\text{Depreciation schedule}} \times \frac{1}{\text{Utilization}}$$

Where:

1. Purchase price = (airframe price + associated spares) + (installed engine price + associated spares)

2. Residual = A given percentage of the purchase price or a fixed dollar amount.

3. Depreciation schedule = As established by the airline's management.

4. Utilization = Flight hours or flights (departures).

4.2.3 AIRFRAME SYSTEMS SPARES INVESTMENT

The magnitude of the spares investment necessary to support aircraft operation merits careful attention by both the airframe and component manufacturers and the airlines.

The basis for the initial provisioning recommendations for the spares to support the introduction of a different type aircraft into an airline is usually the airframe and component manufacturers' reliability predictions (new aircraft) or airline experience (used or inservice aircraft).

Airlines also provide an input into the spares provisioning program based on present and future management philosophy with regard to in-house or out-house agency repair for each component, subcomponent and piece part.

Airline managements must evaluate all of the available options peculiar to each route structure and set of operating constraints in order to arrive at the most cost effective level of spares investment. In addition, the aircraft maintenance program must be tailored to achieve high levels of airworthiness and dispatch reliability with minimum spares support requirements.

Many airlines have developed proprietary computer programs which are utilized to determine the total quantities of spares necessary to support field station allocations, transit time between the field and the repair stations, and repair turnaround times. These programs usually take the following parameters into consideration:

1. Number of stations the aircraft will operate into

2. Frequency of flights per station

3. In-house or outside service repair

4. Predicted component removal or repair rate

5. Transportation time between field and repair station

6. Repair station processing time in calendar days

7. Specified percentage of the times each stocking field station will have a spare component (LRU), subcomponent, repair, or piece part when needed

8. Percentage of time the repair or replacement action can be planned to occur at a station stocking the needed spare

9. Spares investment limitations (if any)

Figure 12 compares the ratio of investment in airframe system spares (LRU and piece parts) versus the capital investment in the airplane less engines and QEC, against a time in service and fleet size base.

As exhibited, investment for spares to support a new aircraft fleet is substantially higher during the introductory phase than later when the fleet size is increasing and the aircraft is reaching maturity. This initial over investment is customary and usually relates to major expense items with the objective of obviating problems that may be associated with long lead time items and to provide a cushion for the initial operation learning experience.

Introduction of a mature aircraft, including those new to an airline, into its fleet will usually result in a lower level of spares investment as advantage is taken of other airlines' learning and reliability experience.

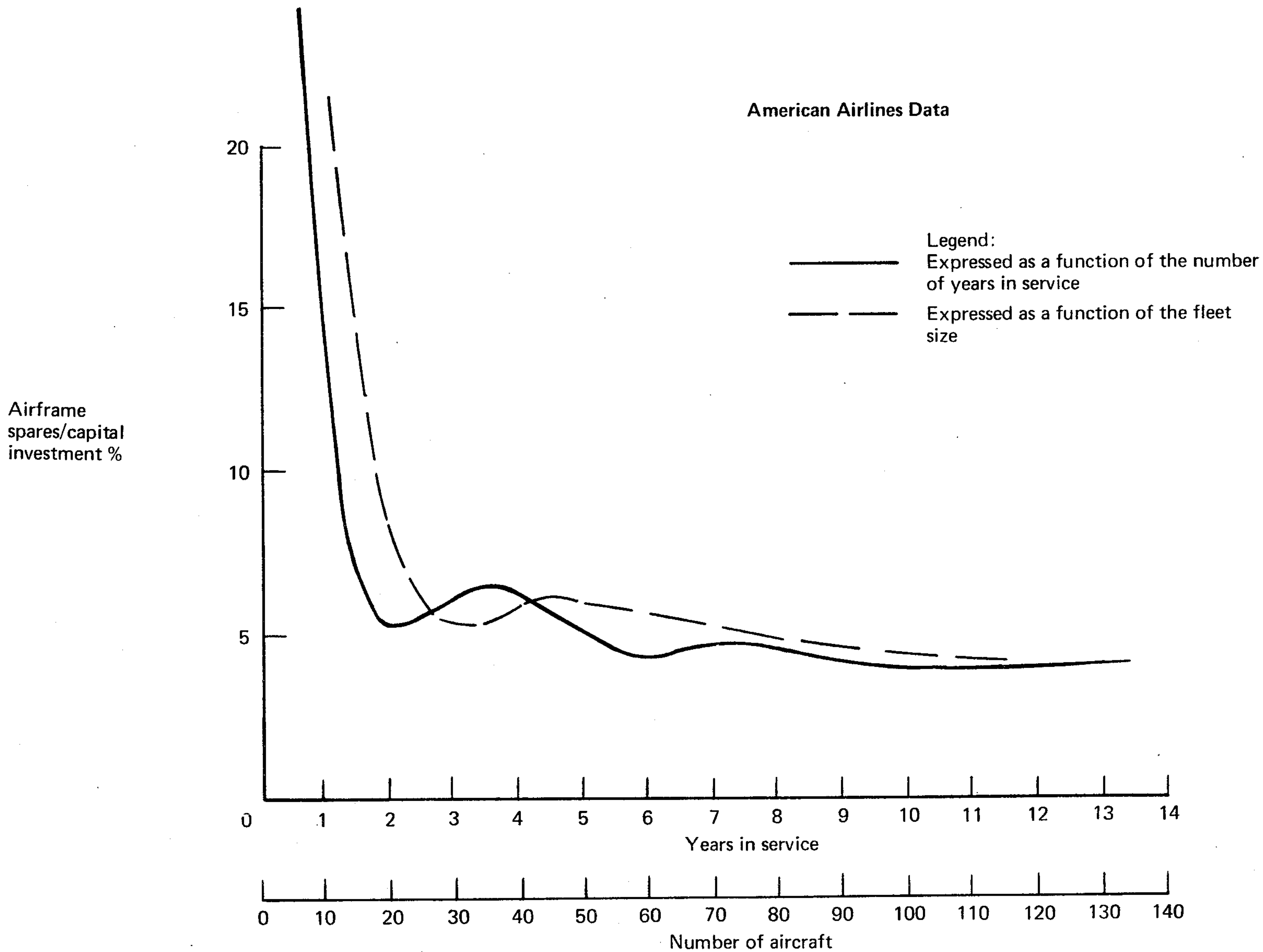

Figure 12.—Ratio of Airframe Spares Investment to Capital Investment

The curve is not intended to display the ratio of spares investment level for a given size fleet, but rather exhibits what the investment ratio level for spares will be as the size of the fleet increases and operational service is accrued.

An increase in fleet size or an increase in the service life should not adversely affect the spares/capital investment ratio once the fleet has matured.

The cost of the spares investment is included in the depreciation equation.

4.2.4 INSURANCE EXPENSE

In order to provide a degree of financial protection in the event of either damage to an aircraft or catastrophic loss, airline managements have established a philosophy with regard to the amount and form of hull and public liability insurance to be carried.

The cost of such insurance, which in the case of aircraft related direct operating costs related primarily to hull insurance, (i.e., the refurbishment and replacement of the aircraft or any part thereof, in the event of damage or loss), will depend substantially on the degree of the airline's self insurance (i.e., amount deductible or capable of being carried internally), the amount of purchased insurance desired (e.g., hull loss coverage only, book value, or replacement cost), the airline's accident history, and theatre of operations. Another consideration is the ability of the insurance industry to cover a potential catastrophic loss from the insurance premium at that point in history and/or other revenues received.

As covered in detail in reference 2, other factors that influence insurance costs are the degree of technological change between the current aircraft type(s) and that being introduced (e.g., narrow body jet to wide body jet or supersonic transport). Other factors include new technological features such as the use of new materials, new wing concepts and extremely high structure temperatures arising from flying at supersonic speeds. Other considerations are cruising at altitudes where cosmic radiation intensity may be a problem, potential midair collision hazard due to reduced reaction time at supersonic speeds, the point in the aircraft's history that the airline introduced it into service, etc. Moreover, many of the current well known problems may, at least in part, become more serious as a result of the introduction of new technology aircraft.

For example, airline insurance rates more than doubled during the introduction of jet aircraft and again doubled during the introduction of wide bodied aircraft. On the basis of good operating experience, the rates declined annually between the introduction of each new type of aircraft until, as seen in recent years, they have again stabilized at a rate approximating that prior to the introduction of jet powered aircraft.

4.2.5 AIRCRAFT SUPPORT EQUIPMENT, FACILITIES AND TRAINING EXPENSES

The equipment, facilities and training expenses required to support the introduction of new aircraft into service was explored to determine if there was a relationship that could be modelled as part of the proposed new aircraft related operating cost methodology.

These indirect jet aircraft size and technology related expenses, which occur, just prior to and during the introductory phase of a new aircraft, represent in the order of 12.5% of the investment in new aircraft.

Since these additional expenses are short range in nature, affected by airline management philosophy regarding the extent of the support to be provided the new aircraft, and the differences that may or may not exist between the new aircraft and the current fleet, it was recognized that neither the potential of a satisfactory correlation parameter nor an awareness of a suitable constant or coefficient to represent these additional indirect expenses, appeared to exist.

Detailed discussion of the Aircraft Support Equipment, Facility and Training expenses are provided in Appendices I and II, respectively.

4.3 AIRPORT/AIRWAYS INTERFACE FEES

The Airport Authorities of cities served by trunk airlines derive a major portion of their operating revenues from the airlines. Most, if not all of the Port Authorities have negotiated agreements with the specific air carriers serving the airport, to the effect that the airlines will at least underwrite the airports bonded indebtedness. The bonded indebtedness and depreciation generally represent about half of the airport expense. Such airline payments are made by way of terminal space rentals, hangar rentals, area leases, fuel service charges, landing fees, etc.

The distribution of the sources of revenue and the airport expenses are illustrated in figure 13 for three different airports. The relative magnitude of these sources is quite varied, from one airport to another.

A more detailed distribution of the operating cost elements and revenue sources from the Los Angeles International Airport Annual Report of 1975 is shown in figure 14. The airport operating expense categories that may relate to aircraft technology and design features, such as runway and taxiway maintenance and repair are minor expense contributors. Runway and taxiway maintenance and repair is to some extent associated with wheel loadings and number of wheel passes of which the largest variable among the various designs is the number of wheels. The total levels of expense and needed revenue are generally related to the passenger traffic through the airport.

4.3.1 LANDING FEES

The domestic landing fee experience of American Airlines is shown in figure 15. The use of maximum landing weight, or in some cases maximum takeoff weight, and the number of flights has been adopted as a reasonable means of assessing the revenue in proportion to aircraft movements. The variation in landing fee rates at the various airports is illustrated in figure 16. For those airports where charges are not based on maximum landing weight, the charges have been converted so that they are so expressed. There is a 15 to 1 difference between the extremes of this sample airport group. The mean value shown represents the mean charge to all aircraft considering the number and types operating at each of these airports.

4.3.2 FUEL SERVICING FEES (Excluding Fuel Costs)

The airport authorities charge the user airlines fuel servicing fees as a means of distributing the indebtedness of the fueling equipment and facilities. The history of these fees, as experienced by American Airlines, is shown in figure 17. The cost to American Airlines in 1976 dollars has remained essentially constant throughout their years of jet aircraft operation. This fee is not associated with the quantity

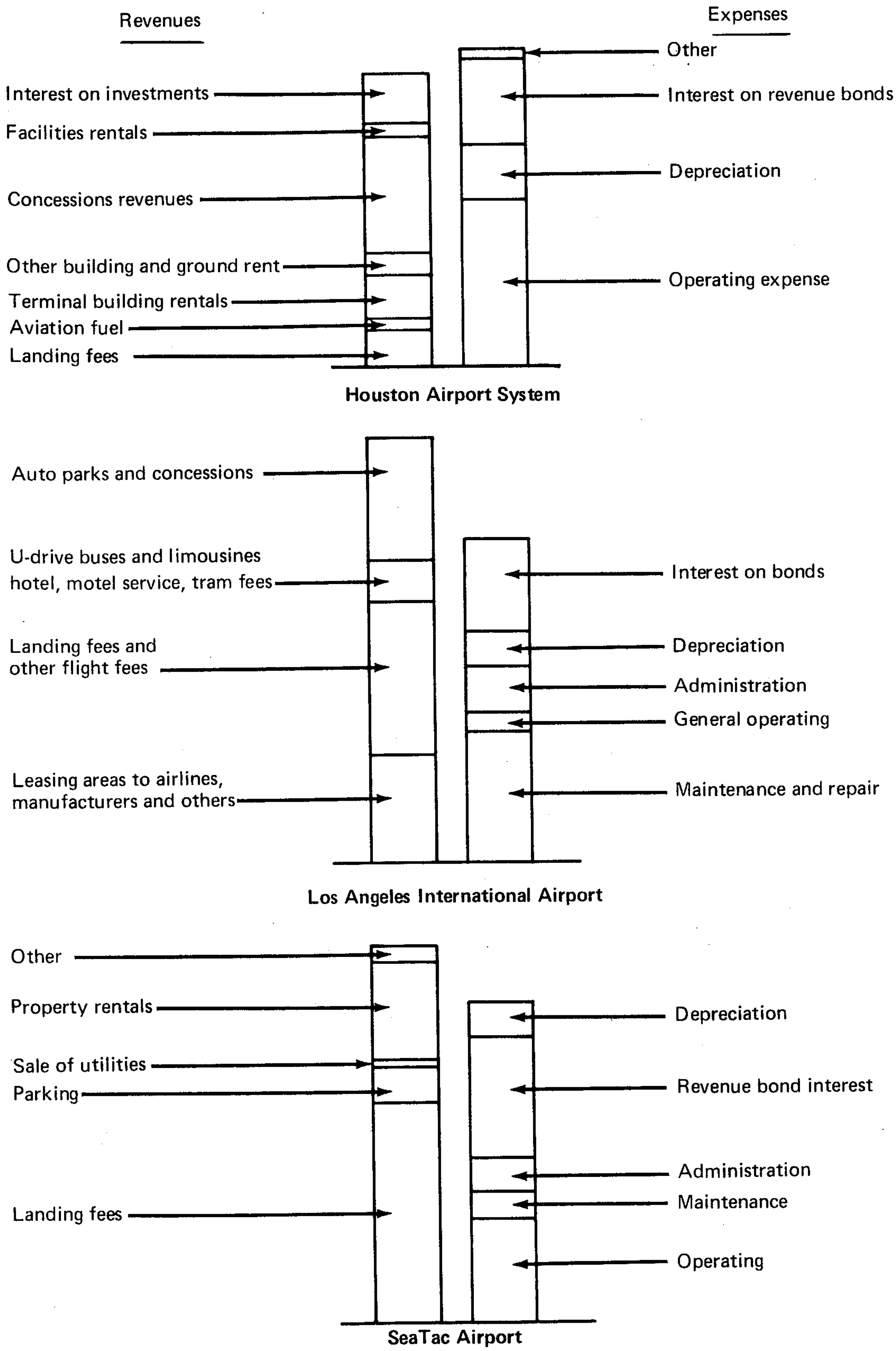

Figure 13.—Distributions of Airport Operating Funds

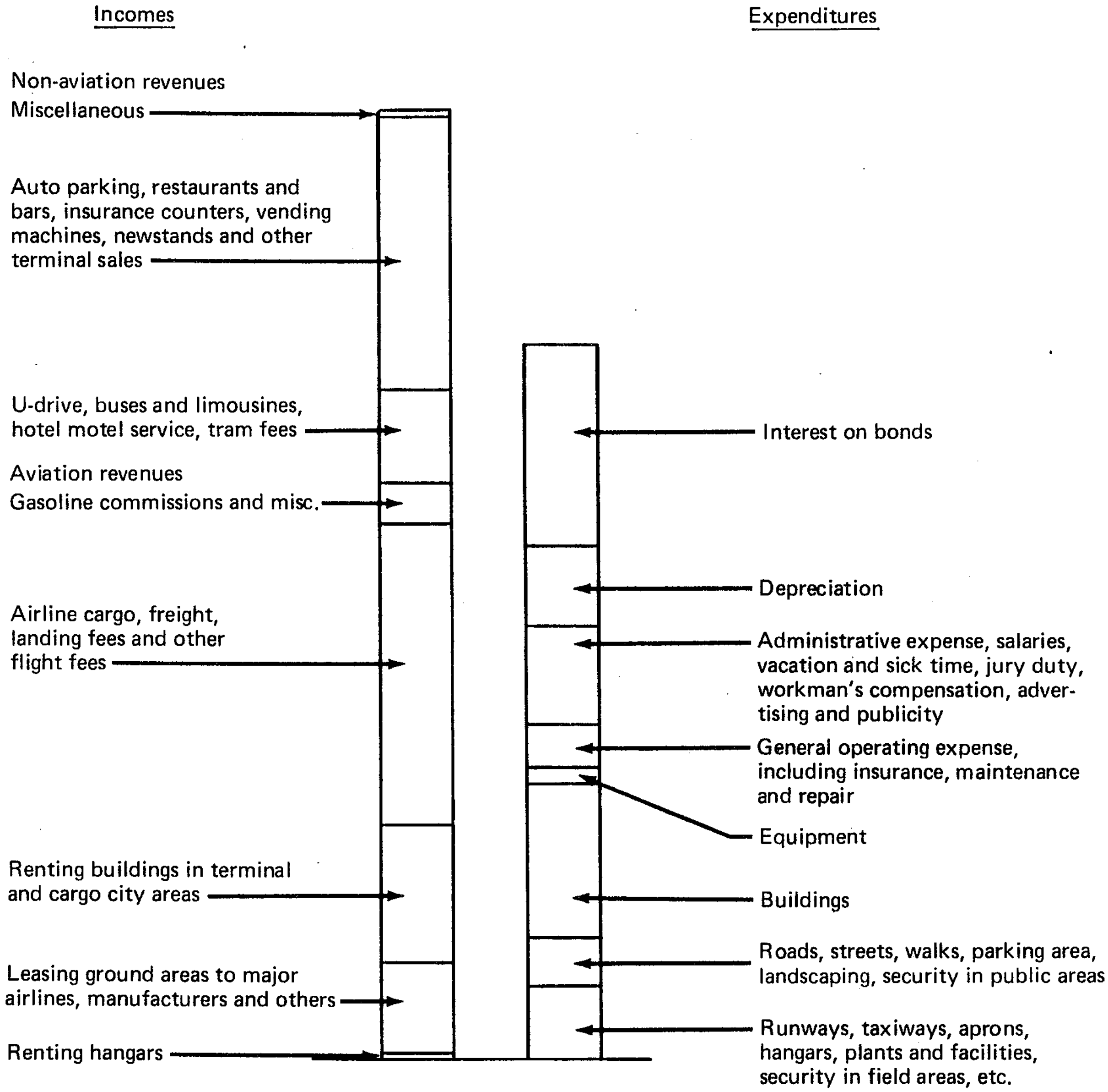

Figure 14.—Distribution of Los Angeles International Airport Incomes and Expenditures—1975

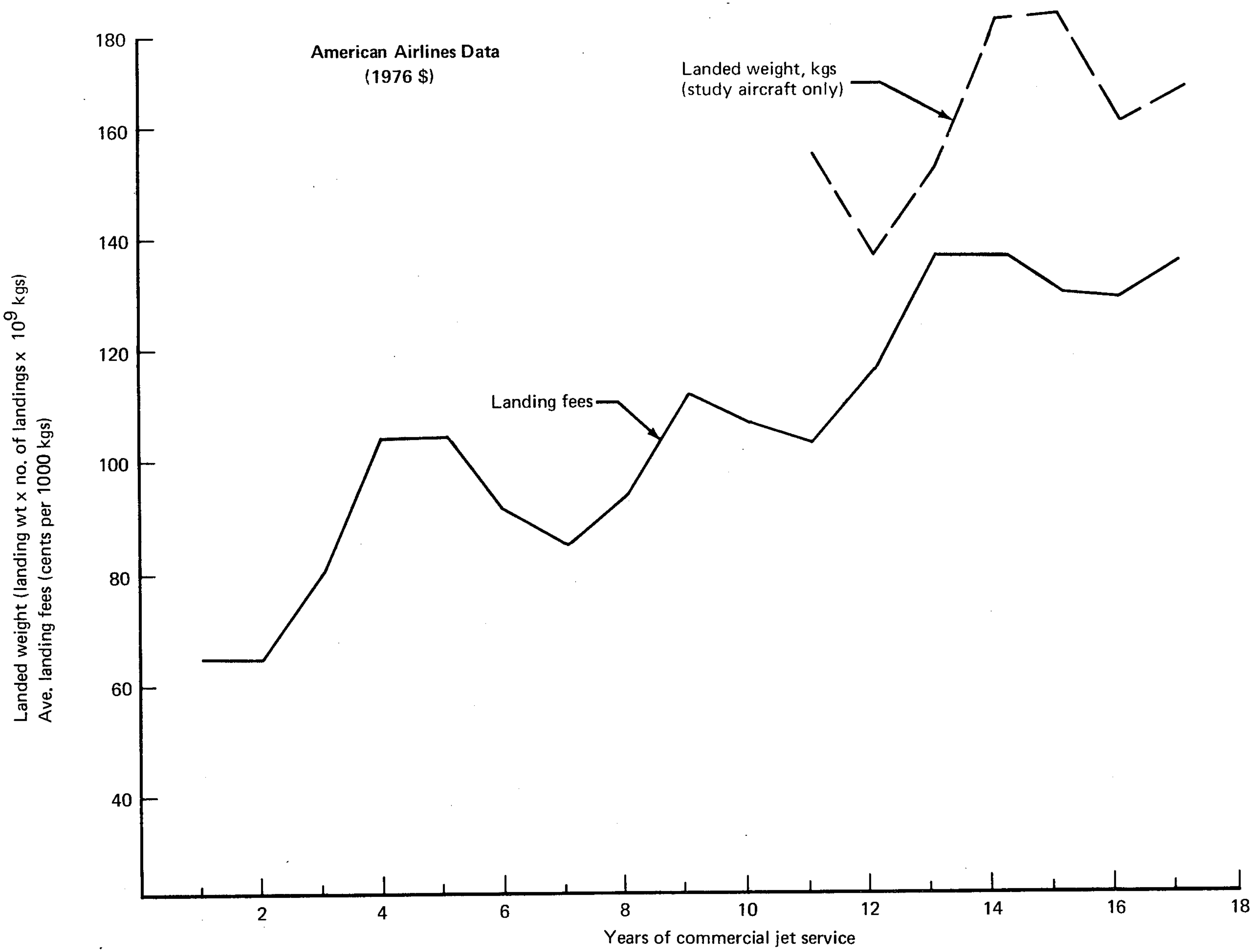

Figure 15.—Trend of Airport Landing Fees—U.S. Domestic

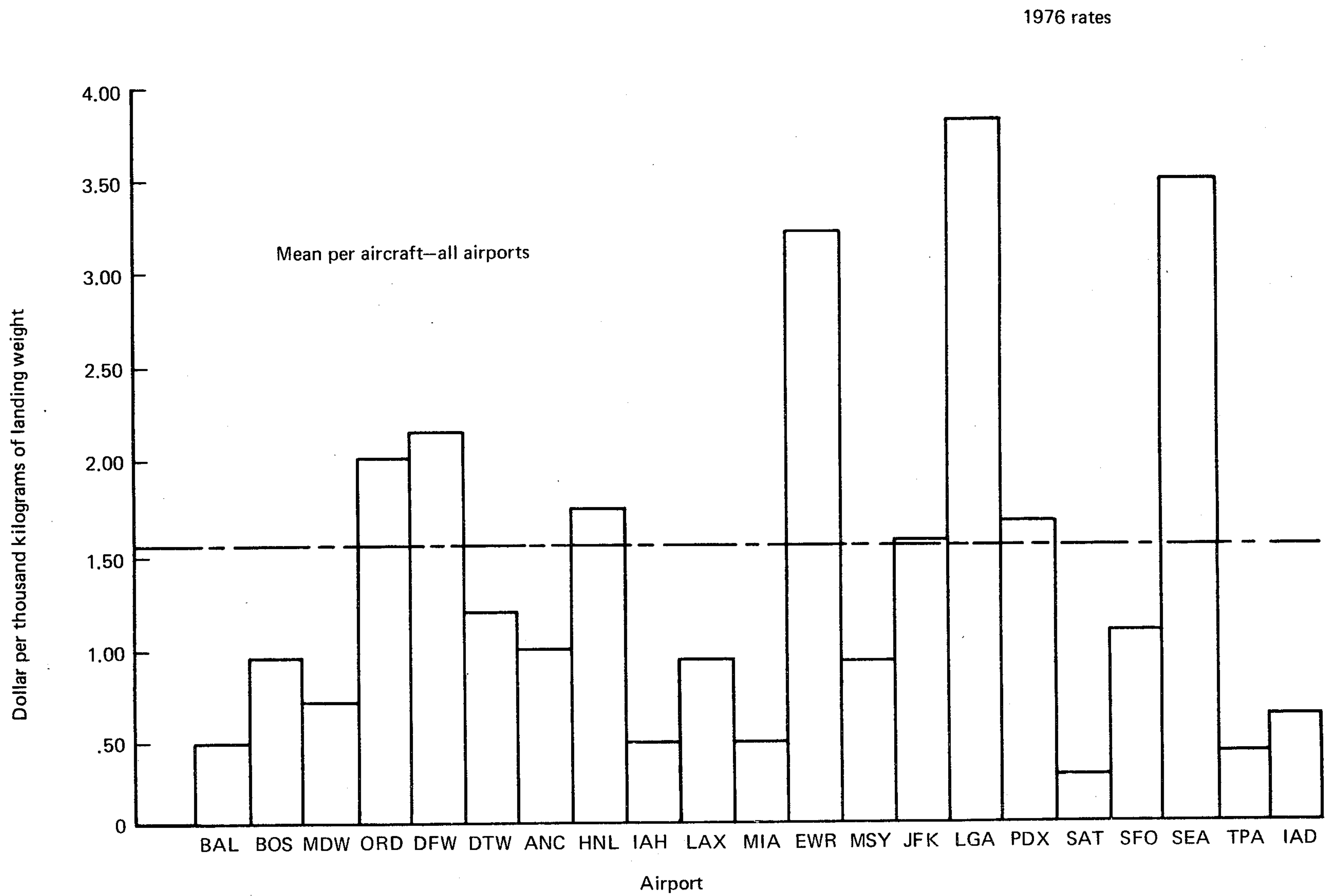

Figure 16.—Airport Landing Fee Rates

American Airlines Data

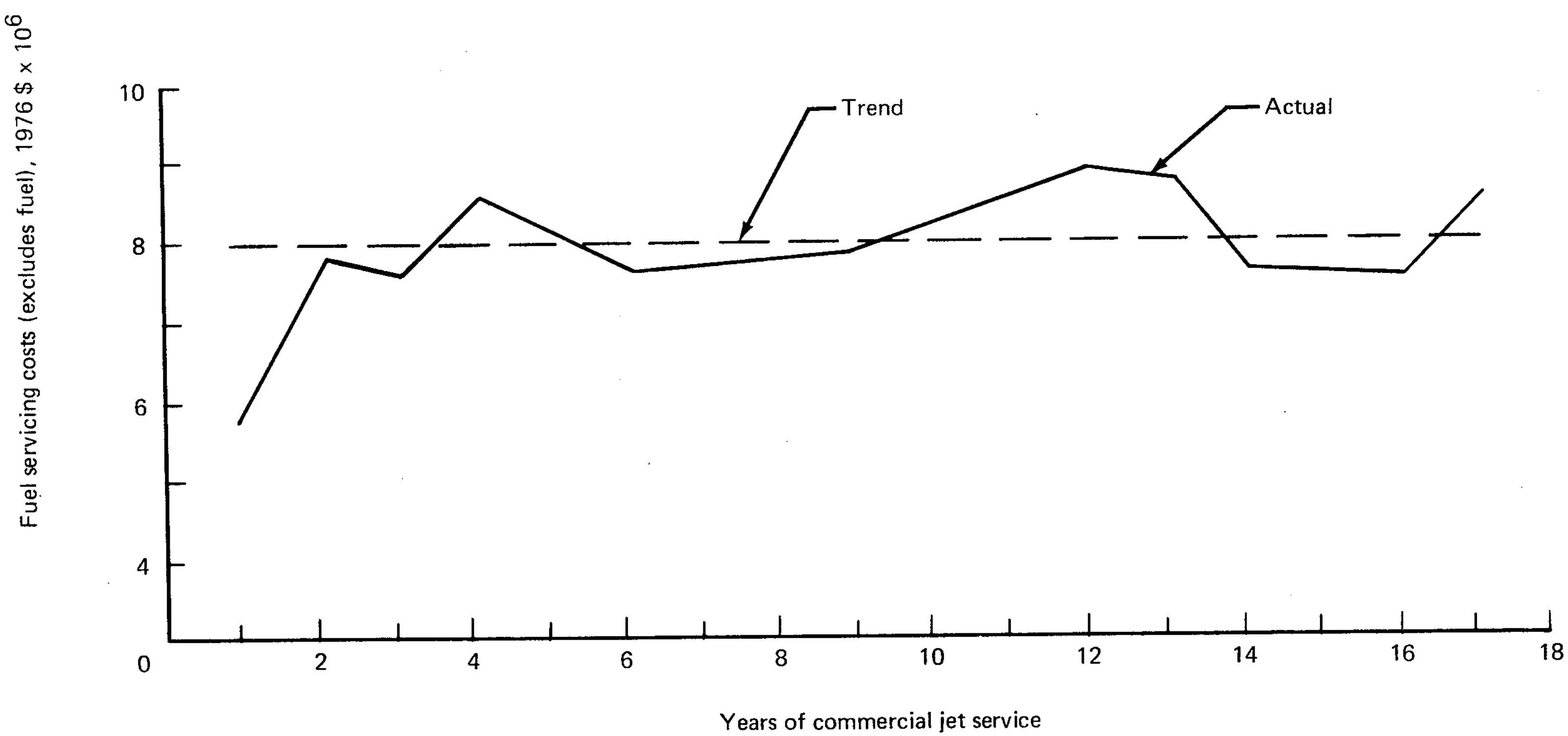

Figure 17.—Fuel Servicing Costs

of fuel purchased, but is the airlines share of having fuel service available at the stations served. As the expense is not related to airplane technical characteristics, except the type of fuel used, it can only serve as a reminder of a potential expense to be born if a different type of fuel is adopted. This expense is approximately .21 cents per liter.

4.3.3 AIRCRAFT CONTROL FEES

FAR 121.99 requires each domestic and international (flag) air carrier to have a reliable and rapid privately owned communication system between its aircraft and its dispatch office. The air carrier must also maintain communications with Air Traffic Control through a government owned set of ground stations. The privately owned communications network must be independent of any system operated by the Federal authorities within the 48 contiguous states. Aircraft air-ground communications expenses are presently treated as an indirect rather than a direct aircraft related operating cost.

The communications network covers both radio, telephone and teletype systems. In recent years, communications have been integrated with computer systems to aid data storage, manipulation and retrieval for various management control and information purposes. (See figure 18.)

Initially each airline established its own communications network. However, as airlines and their routes expanded, demands by each carrier for additional individual radio frequencies soon caused an almost saturated condition for the assigned radio frequencies at the major airports. Further, there was a duplication of hardware and manpower neither of which was fully utilized.

Recognizing that soon these conditions would occur at the majority of points served, the major airlines pooled their resources under a separate company, Aeronautical Radio Incorporated (ARINC). With the passage of time, ARINC not only provided the air to ground communications network, but also established basic specifications for most aircraft avionic equipment.

Technology has improved air ground radio communications. For example, as transistors and other solid state devices replaced tube type equipment, the avionic units have diminished substantially in size. Component reliability, cost, weight, power requirements, resistance to shock and vibration, and signal quality have also improved as a result of these changes.

Air to ground radio communication is achieved by means of voice radio. This form of communication is relatively slow compared to that which can be accomplished by the transmission of digitized electrical signals. Much of the data being verbally transmitted today could be in the form of such a digital data link where the digital signals are transmitted and received between airborne hardware and ground based computers. Developments are underway to institute this type of real time data link between the aircraft and the ground which would facilitate the automatic transmission of data to and from the aircraft. These data will comprise such matters as enroute weather conditions, fuel-on-board reports, out-off-on-in-times, estimated times of arrival, etc., which comprises 80% of the intra company air-ground radio communications traffic. For air traffic control purposes flight clearance, flight plans, terminal weather and traffic conditions could also be relayed.

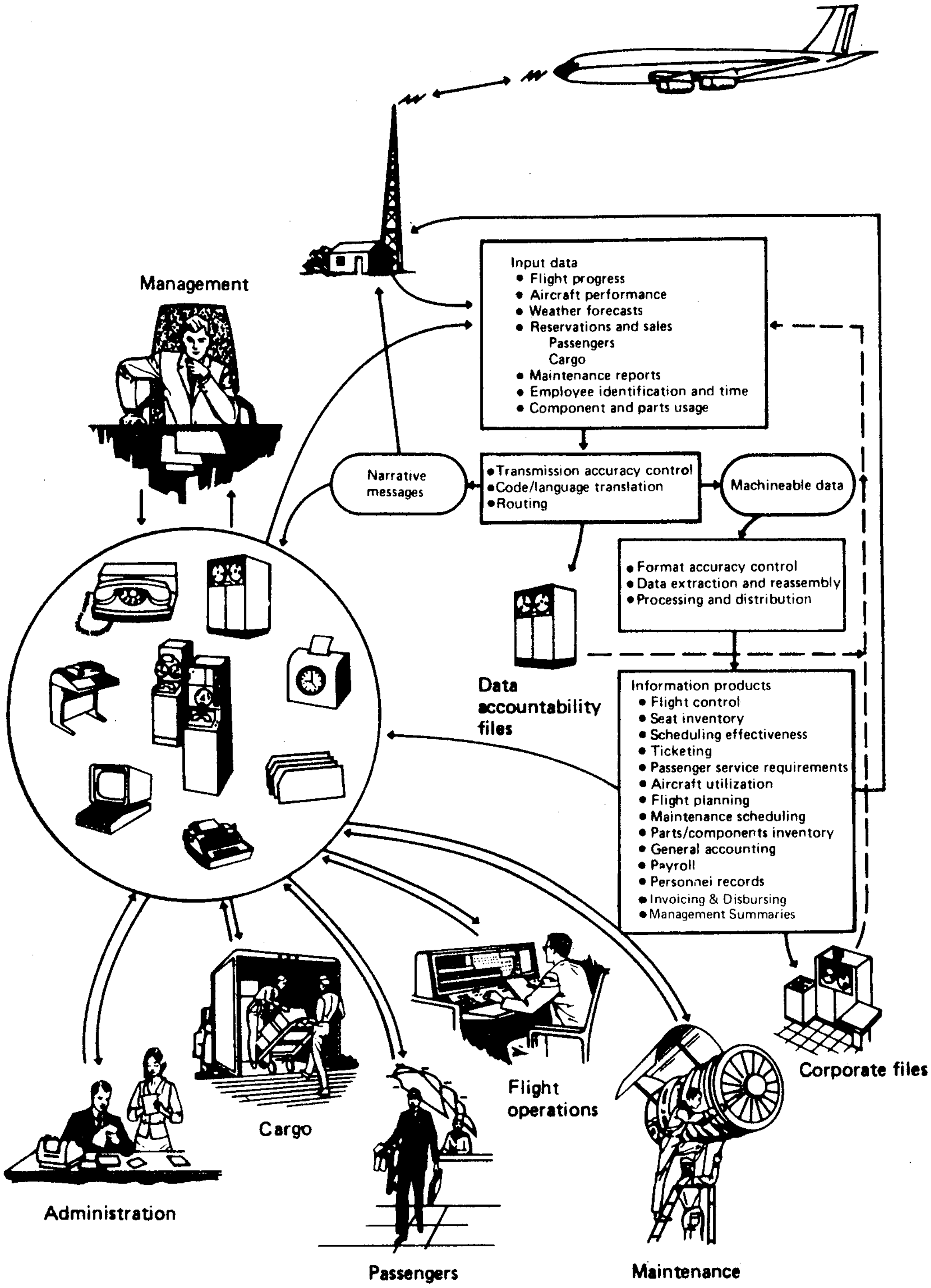

Figure 18.—Air/Ground Communications Network

The data link system will increase the speed of data acquisition and improve the accuracy by eliminating language misunderstanding (foreign and accent). For example, routine air/ground radio messages transmitted in the form of a verbal report by voice radio can be transmitted in approximately 1/500 of the time using the data link system. In addition, both onboard and ground equipment can store the data until either is ready to communicate.

An onboard message printer and keyboard are planned with certain of the keys to be programmed for special messages. Expansion of this communication system has been envisioned to cover passenger service requirements related to air travel through an auxiliary data terminal. This unit would be used for alternative or other flight arrangements, customer requests, seat availability, etc. Through a satellite, the data link could be established worldwide.

Improved air/ground data exchange is available now and the improvements in speed will more than offset increased costs while preserving the radio frequency spectrum. Hence, the current average cost of about $7 per departure (see figure 19) for air/ground communications is expected to be reduced by 40% after 1979, to a cost of about $4 per departure.

Hence for the purposes of the operating cost methodology described in this report, two expense parameters will be required for the communications portion depending on whether the aircraft is fitted with data link or not.

4.4 AIRCRAFT OPERATING EXPENSE

4.4.1 WEIGHTS AND SEAT COUNTS

American Airlines' large fleet of airplanes was purchased and delivered over a span of many years. Airplanes of the same basic model, if delivered several years apart, may have considerable variation in weights, equipment, engine rating, or fuel capacity. These changes may be caused by improvements in the airplane or by changing requirements within the airline. To simplify the analysis, a particular version of each model was selected as representative of the airplane types in American Airline's fleet. For this, the maximum takeoff gross weight (MTOGW), maximum landing weight (MLW), and operating empty weight (OEW), as shown in table 5 were used throughout this study.

Logic suggests that the maintenance cost of some systems should be related to the number of seats. The most obvious example is ATA 25, Equipment and Furnishings, which consists primarily of passenger seats and other cabin furnishings. The logic of using seat count as a parameter for maintenance cost in this case is apparent, but the question then arises regarding which seat count to use.

The number of seats is a parameter which can be easily varied, even after an airplane is in service. The seat count will vary from one airline to another for a given model, and may vary between airplanes in an airline's fleet, depending on the requirements of the routes being flown. Changing requirements may cause the airplane seating layout to change from year to year. In recent years the trend has been to reduce first class seating, with a corresponding increase in tourist class seats, and often an increase in total seat count.

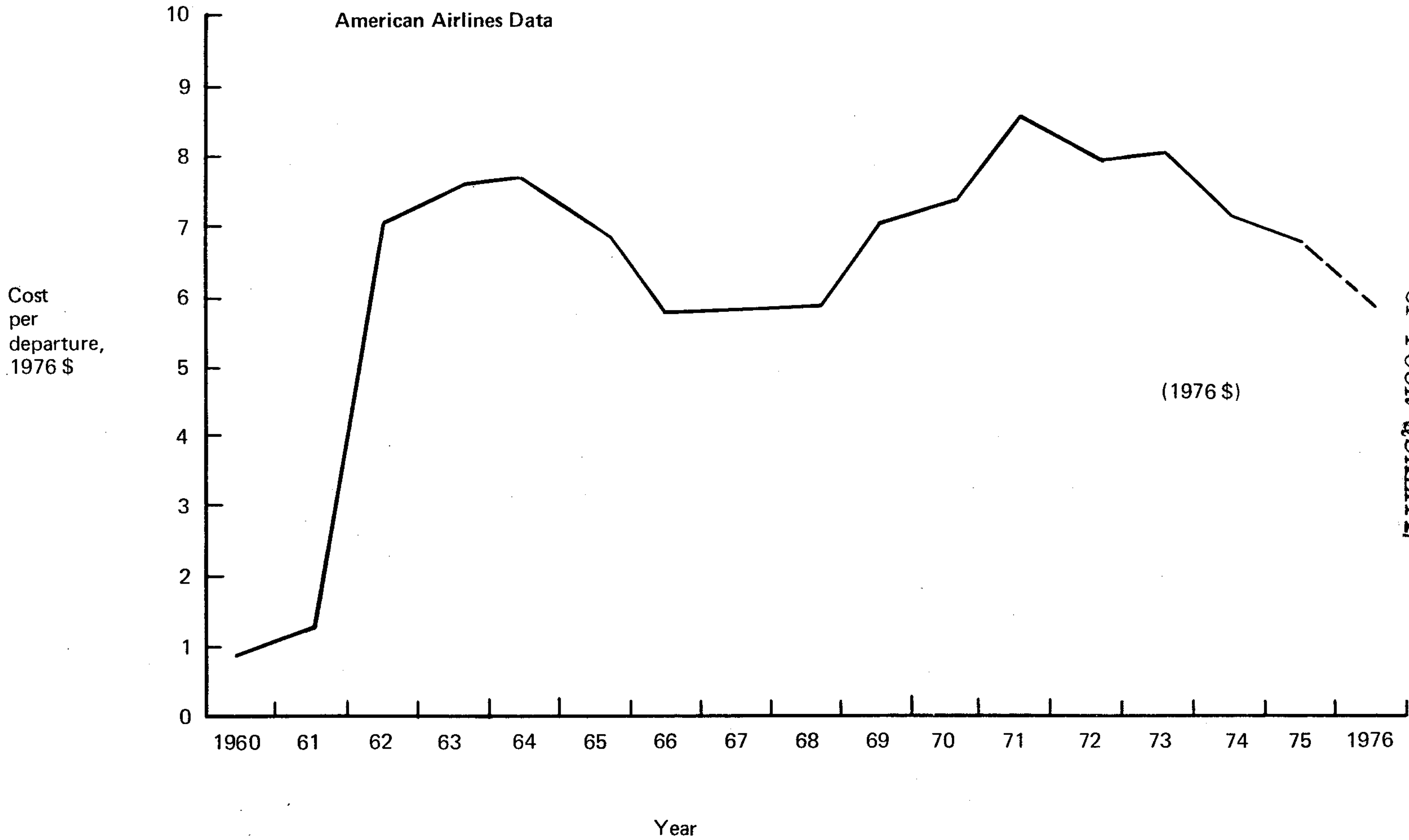

Figure 19.—Air/Ground Communications Expense by Calendar Year

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Table 5.—Table of Weights and Seat Counts Used in Study

	727-100	727-200	707-100B	707-300B	707-300C	DC-10	747	737-200
Spec seats	103	131	144	157	155	282	423	95
MTOGW-kg	72,575	78,018	117,027	151,092	151,092	185,973	322,051	52,163
MLW-kg	62,369	68,039	86,183	97,522	112,037	152,861	255,826	46,720
OEW-kg	39,347	45,361	56,788	64,724	65,376	104,213	163,033	28,236
AFW-kg	32,921	37,003	46,065	52,368	54,579	85,201	131,372	23,496

On the narrow body airplanes, seat counts usually vary only with seat pitch and galley provisions; on the wide body airplanes many airlines have lounges and/or below-the-floor galleys, so that the inservice seat counts may be considerably different from the manufacturer's specification layout. On the 747, for example, the upper deck is commonly used as a lounge, and therefore the seats are not counted as revenue seats. Nevertheless, the seats and other furnishings in the lounge are used and must be cleaned and maintained. Most of the American Airlines 747 fleet currently have 366 seats, but three are fitted with 424 seats for certain routes.

Because of these factors, the seat counts used for this study, listed in table 5, are defined for a consistent comfort level, with uniformly defined first class/tourist class mix, seat pitch, and allowances per seat for galleys, lavatories, and storage. These seat counts, which will be referred to as spec seats throughout this report, are somewhat higher than current typical airline seating, particularly for the larger airplanes. For seat counts based on other than the assumptions used here, the ratio of actual seats to spec seats (consistent with those used here) may be used, with judgment, to determine seat related maintenance cost.

4.4.2 FLIGHT CREW PAY

FAR 25.1523, FAR 25 Appendix D, FAR 121.385 and FAR 121.387 specify the minimum flight crew complement, composition and qualifications for operation of large commercial transport aircraft.

FAR 121.387 requires that aircraft certificated before January 2, 1964, having a maximum takeoff weight in excess of 80,000 lb (36,287 kg), have one member of the flight crew qualified to perform the duties of the Flight Engineer. For aircraft certificated after January 1, 1964, the requirements for Flight Engineer capabilities are on the basis of the influence of the aircraft design on flight deck work load. (FAR 25.1523 and FAR 25 Appendix D.)

In general, it has been the practice to initially certificate the narrow bodied twins (BAC 1-11, B737 and DC9 aircraft) for two crew operation, whereas other aircraft, such as the Boeing 727, 707 and 747, Lockheed L1011, McDonnell Douglas DC8 and DC10, etc., were certificated for operation with 3 crew members. In certain cases, the airlines were instrumental in causing either the initial or a follow-on certification of an aircraft to be with a three crewmember complement because of anticipated cockpit workload, and/or related pressure from the flight deck unions. Nontechnology factors can, therefore, negate the effects of technological improvements.

As flight deck crew expense makes up a large portion (20 to 25%) of current Direct Operating Costs, technological improvements that can reduce cockpit workload and, in turn, reduce the cockpit complement without compromising safety could have a very beneficial effect on airline economics. An excellent example of this is the redundancy of Navigators on International Flights created by the introduction of the Inertial Navigation System.

In order to provide a pay scale commensurate with the responsibility associated with the aircraft size, complexity (capital investment), etc. and to share in aircraft revenue generation (productivity), flight crew pay scales in the U.S. for subsonic airplanes have been arbitrarily based on maximum aircraft gross weight and aircraft speed. Seniority of service is also recognized through a longevity pay formula. A basic hourly rate is the fourth element used to compute flight crew pay. Co-pilot and third flight deck crew member, where applicable, salaries are generally each a percentage of the Captain's pay scale.

Although the flight crew compensation formula varies from airline to airline, competitive pressures and union negotiations assure that minimal differences exist between equivalent flight crew members of one airline and another.

Although the distribution of pilot seniority varies from airline to airline, (the average seniority of flight crew at American Airlines on January 1, 1976 was 14.8 years) for the purposes of developing the methodology, it has been assumed that flight crew member seniority at American Airlines is representative of the industry.

Direct flight crew compensation per aircraft block hour, expressed as a function of aircraft gross weight, is shown in figure 20, and is considered representative of flight crew expense.

Flight crew compensation is affected by the amount of time a crew spends on duty. Allowance is made for the non-flight time the crew spends preparing for a flight at the originating through or turn around stations, and the subsequent debriefing period at the end of the flight or working day. The allowance for this non-flight time is a function of the flight hourly pay. Additional factors in compiling flight crew pay are the minimum and other guarantees. These pay guarantees assure that all flight crew receive the most advantageous compensation calculated on the basis of the number of hours flown and/or on duty.

Figure 21 shows the various correlations that were developed to determine which factors for hourly pay, aircraft gross weight and aircraft speed produced the best correlation with actual crew pay per aircraft block hour. The best correlation could be achieved if the speed factor was ignored.

This is not surprising if we consider that aircraft cruise speeds today tend to vary little by aircraft type, but instead are varied to optimize schedule needs, cost of the operation and competitive pressures. Figure 22 further supports this. Thus, direct flight crew pay per aircraft block hour for a 3 man cockpit crew can be expressed as follows:

Pay (1976 \$)/block hour = 174 + 45.2 (maximum aircraft gross wt, kg/100 000)

or

174 + 20.5 (maximum aircraft gross wt, lbs/100 000)

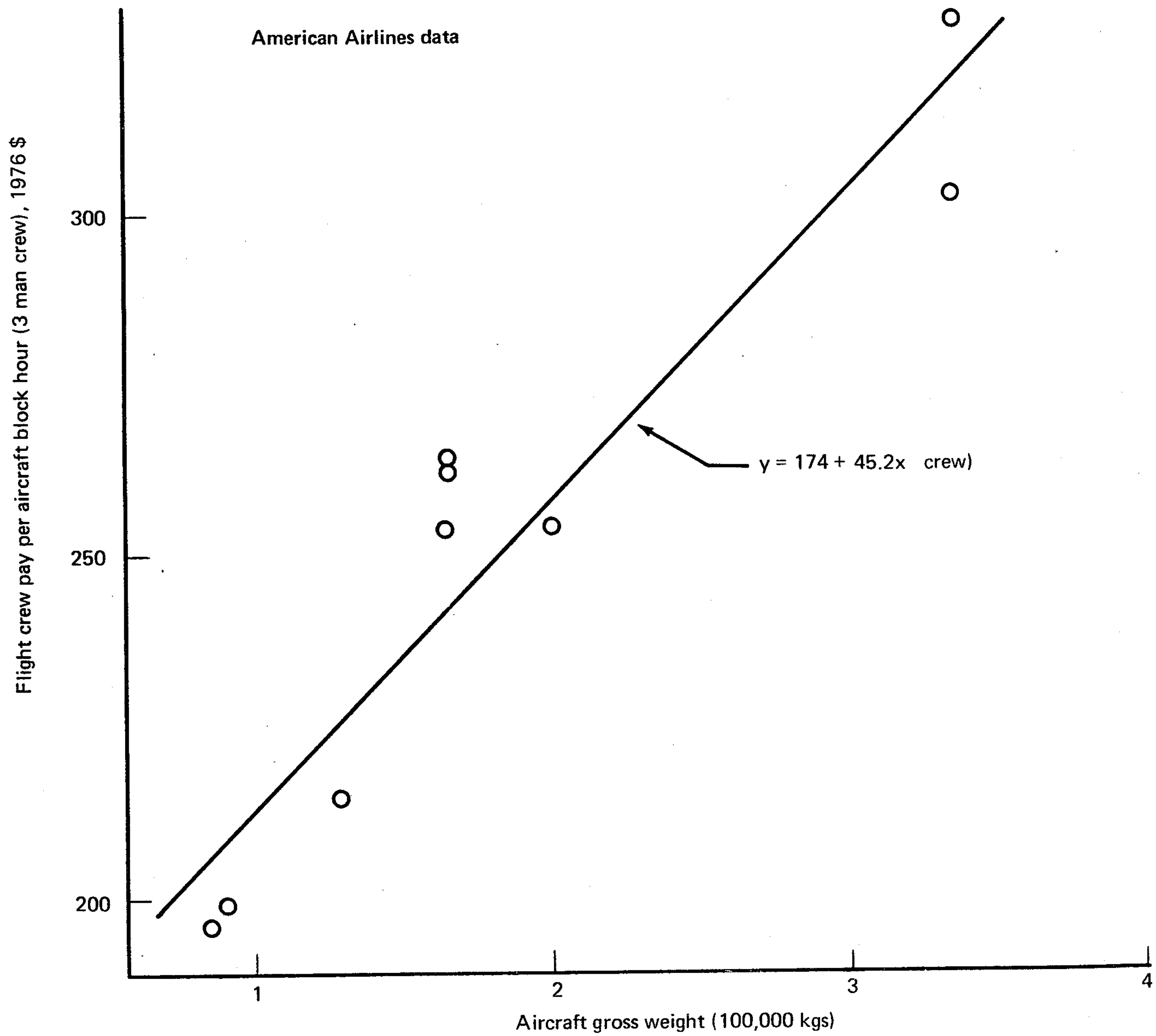

Figure 20.--Distribution of Flight Crew Pay Per Block Hour as a Function of Aircraft Gross Weight

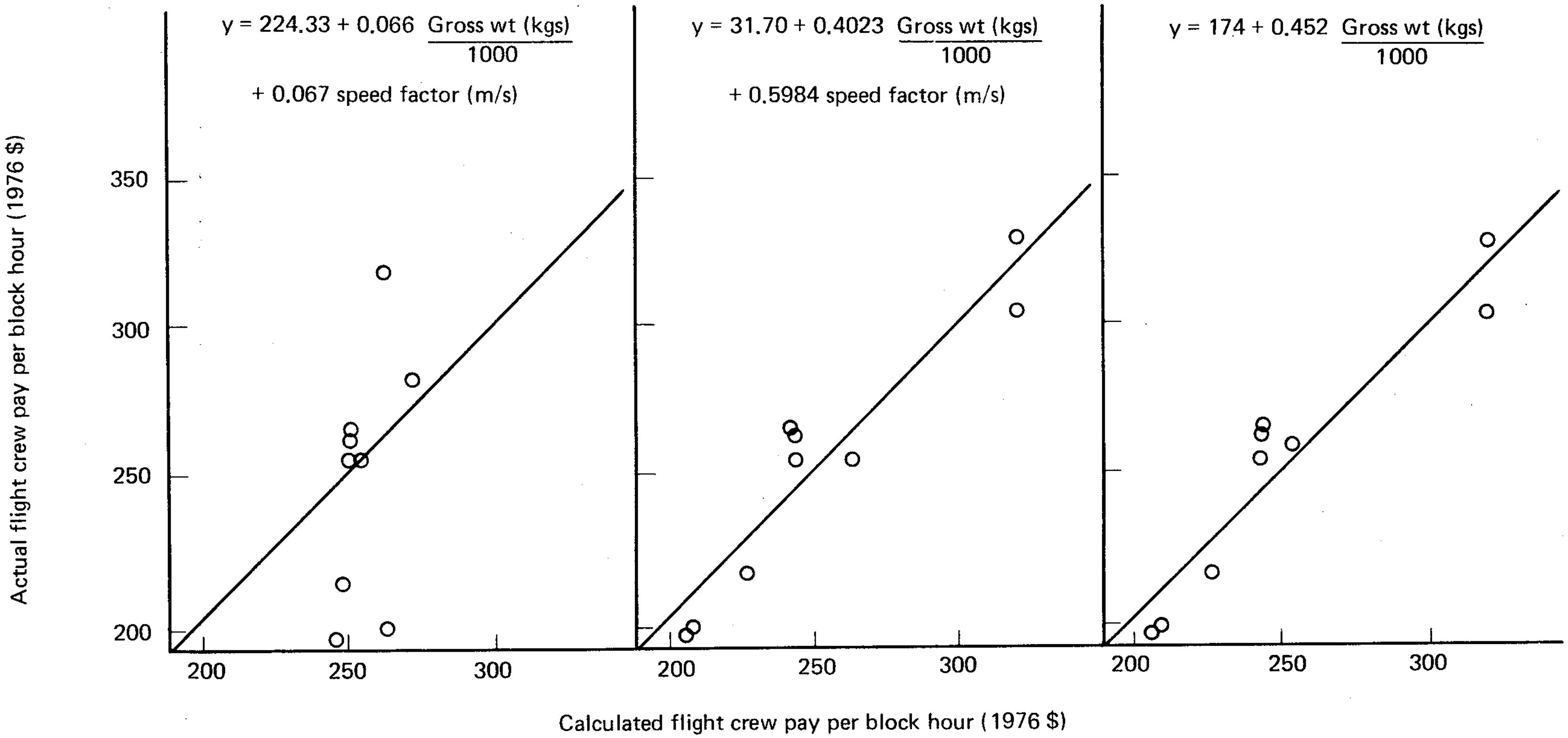

Figure 21.—Comparison Between Actual and Calculated Flight Crew Pay Per Aircraft Block Hour for a 3 Man Cockpit Crew (1976 $)

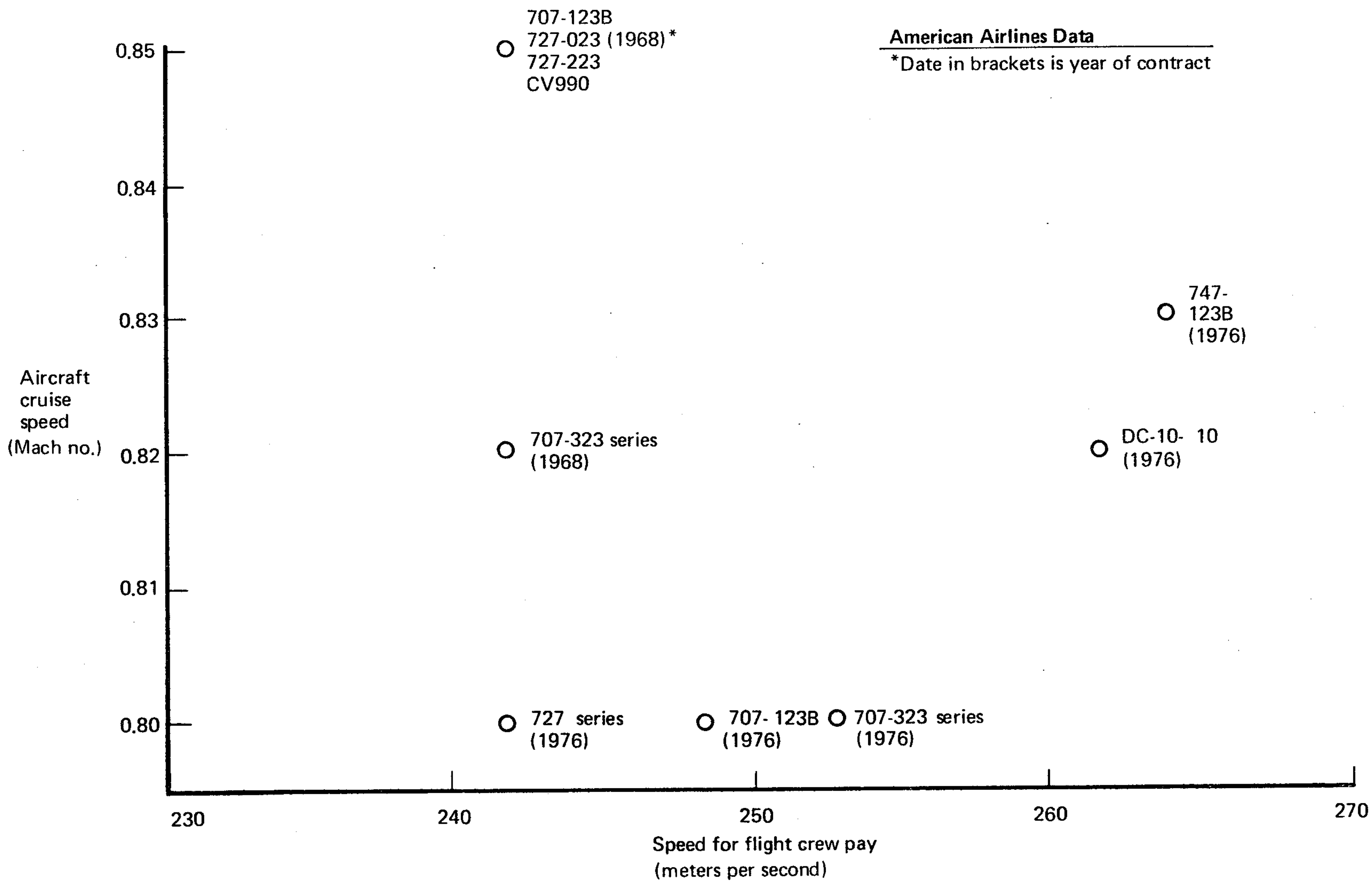

Figure 22.—Comparison Between Aircraft Cruise Speed and Flight Crew Pay Speed

Note: Direct flight crew pay is only the salary portion of flight crew costs. It does not include fringe benefits nor incidental costs associated with crew expenses, such as overnight charges, local transportation, etc.

Utilizing the preceding developed equation, figure 23 displays the average direct flight crew pay per departure on the basis of aircraft maximum gross weight and average flight length. American Airlines' actual flight crew pay per departure by aircraft type is shown for comparison purposes and highlights the effect of seniority on crew pay.

To determine the differences of two flight crew members versus three for a given aircraft type, direct flight crew block hour pay data for six airlines operating Boeing 737-200 Series aircraft with two and three man crews and six airlines operating DC9-30 Series aircraft with two man crews was developed, without regard for the gross weight differences, from CAB form 41 reported data. Of these airlines, three 737 operators utilize three flight crew members, and three initially utilized three crew members and subsequently changed to a two crew member operation. The developed data is displayed in figures 24 through 28 and reveals that while there is an incremental pay differential between carriers operating two and three flight crew member cockpits, the advantage gained by carriers changing from three flight crew members to two has, so far, been minimal. It is, however, in indirect flight crew costs (fringe benefits, etc.) that there is a benefit to airlines by the reduction of cockpit crew complement from three to two members. These indirect costs generally represent an additional 25 to 30% (depending on the airline) of flight crew direct costs.

On this basis, when considering the introduction of a new aircraft and determining the advantages of two flight crew members versus three, flight crew introductory costs for a two man crew may be considered 75% of that arrived at for three crew members. However, as demonstrated by the previous data, recognition should be made that this financial advantage may be short term.

The method used by the airlines to determine the pay relationship between the various cockpit crew members also supports this rationale. Co-pilot pay is 66% of the Captain's pay and the third crew member is 90% of the co-pilot's pay or 60% of the Captain's pay. This means the third crew member pay represents approximately 25% of the total three man crew flight pay.

It is worthy of note that the layoff of flight crew personnel during a recessionary period serves little purpose in reducing the effects of flight crew pay on direct operating costs. Since it is the less senior (and hence lower paid) flight crew members that are declared surplus, and higher paid senior flight crew members are retained, (unless an early retirement program is also initiated and encouraged) the average flight crew pay and its contribution to direct operating cost increases.

As stated earlier, improvements in technology have, and can continue to have, a significant effect on the impact of flight crew pay on an airlines operating costs.

Improvements in technology that will make significant reductions in cockpit workload and enhance the safety aspects of aircraft flight could eventually result in the need for only two crew members in an aircraft cockpit regardless of aircraft size and/or stage length.

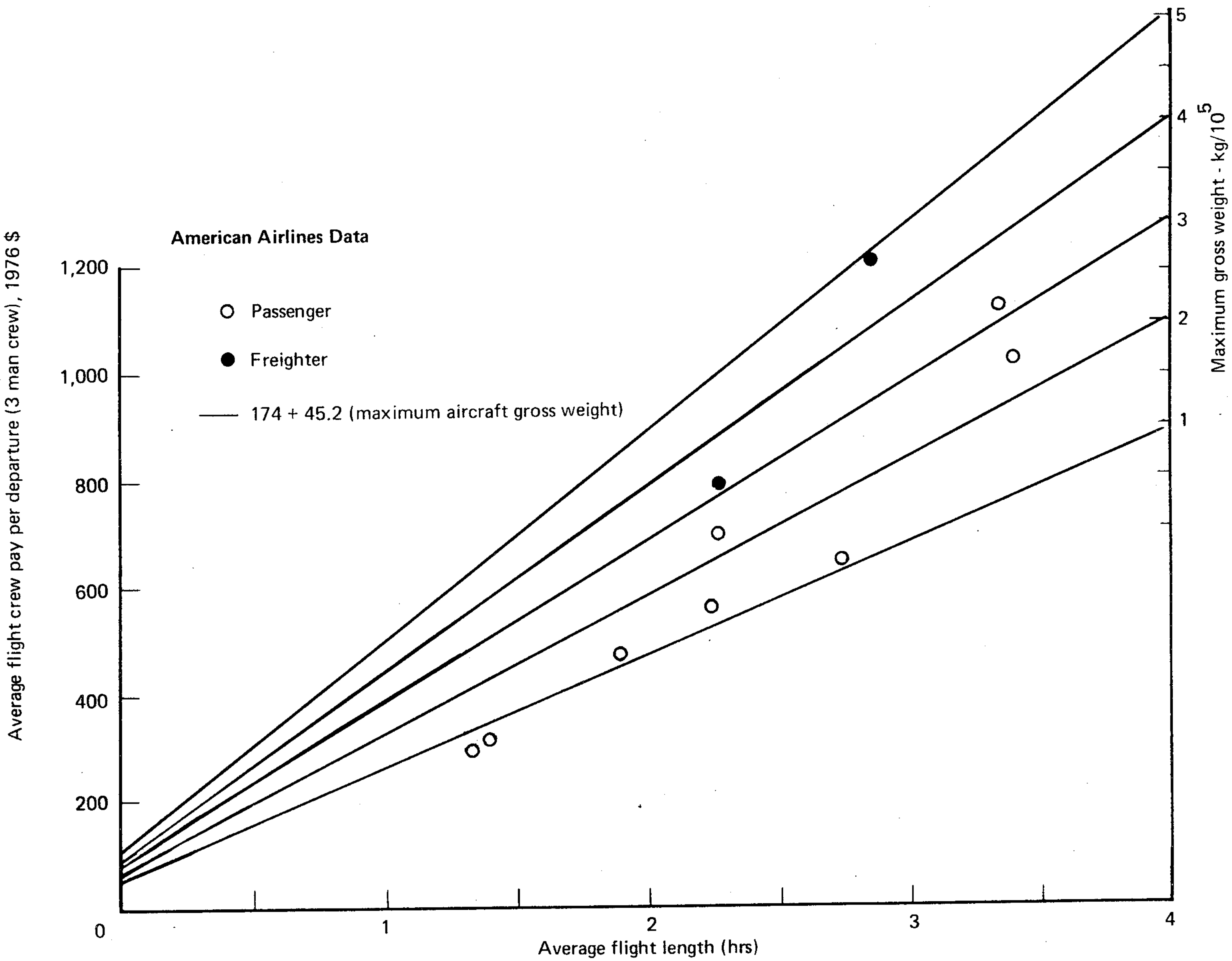

Figure 23.—Distribution of Flight Crew Pay Per Departure as a Function of Flight Length and Gross Weight

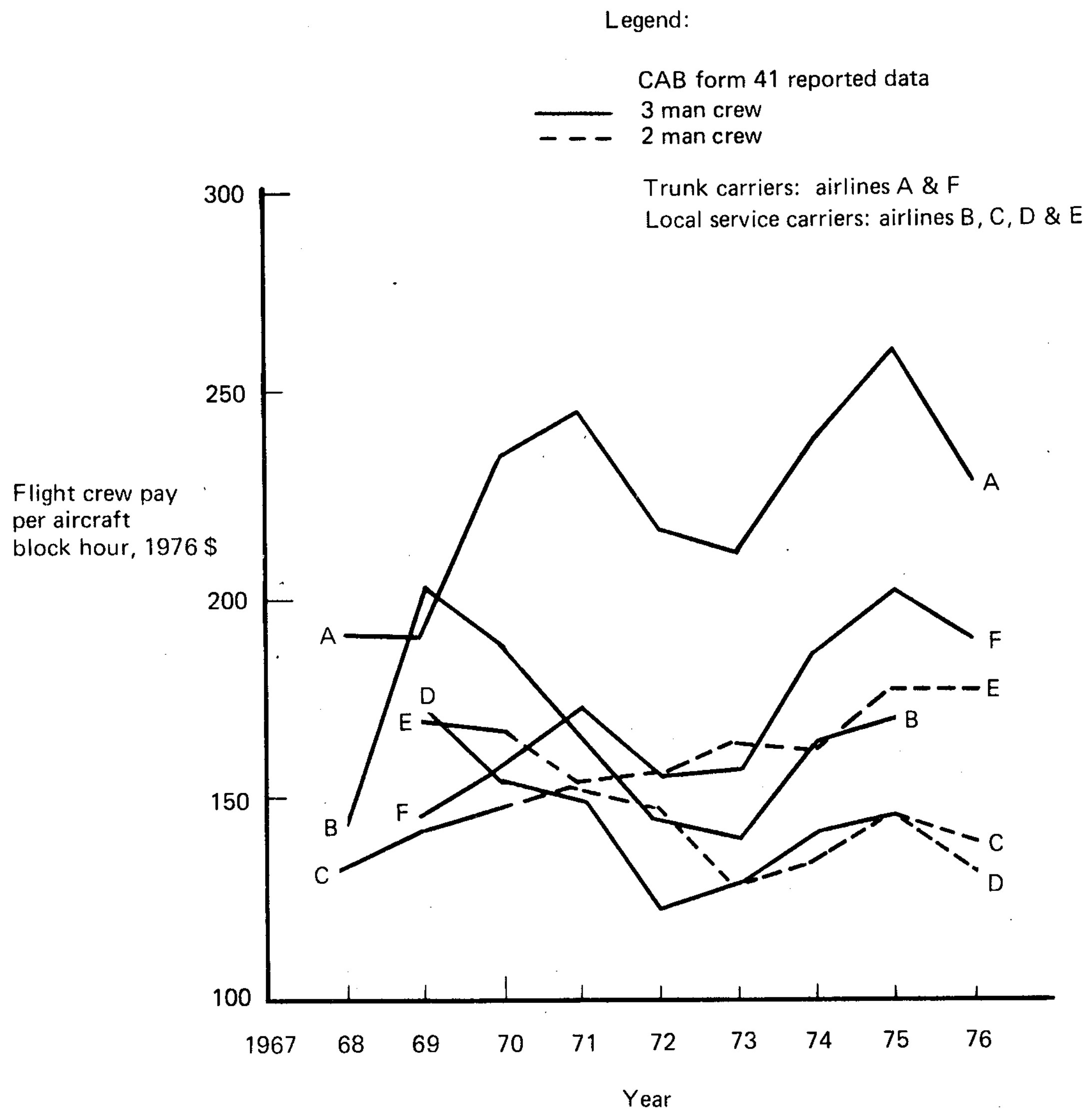

Figure 24.—Comparison of Flight Crew Pay for Boeing 737 Series Aircraft in U.S. Domestic Operation

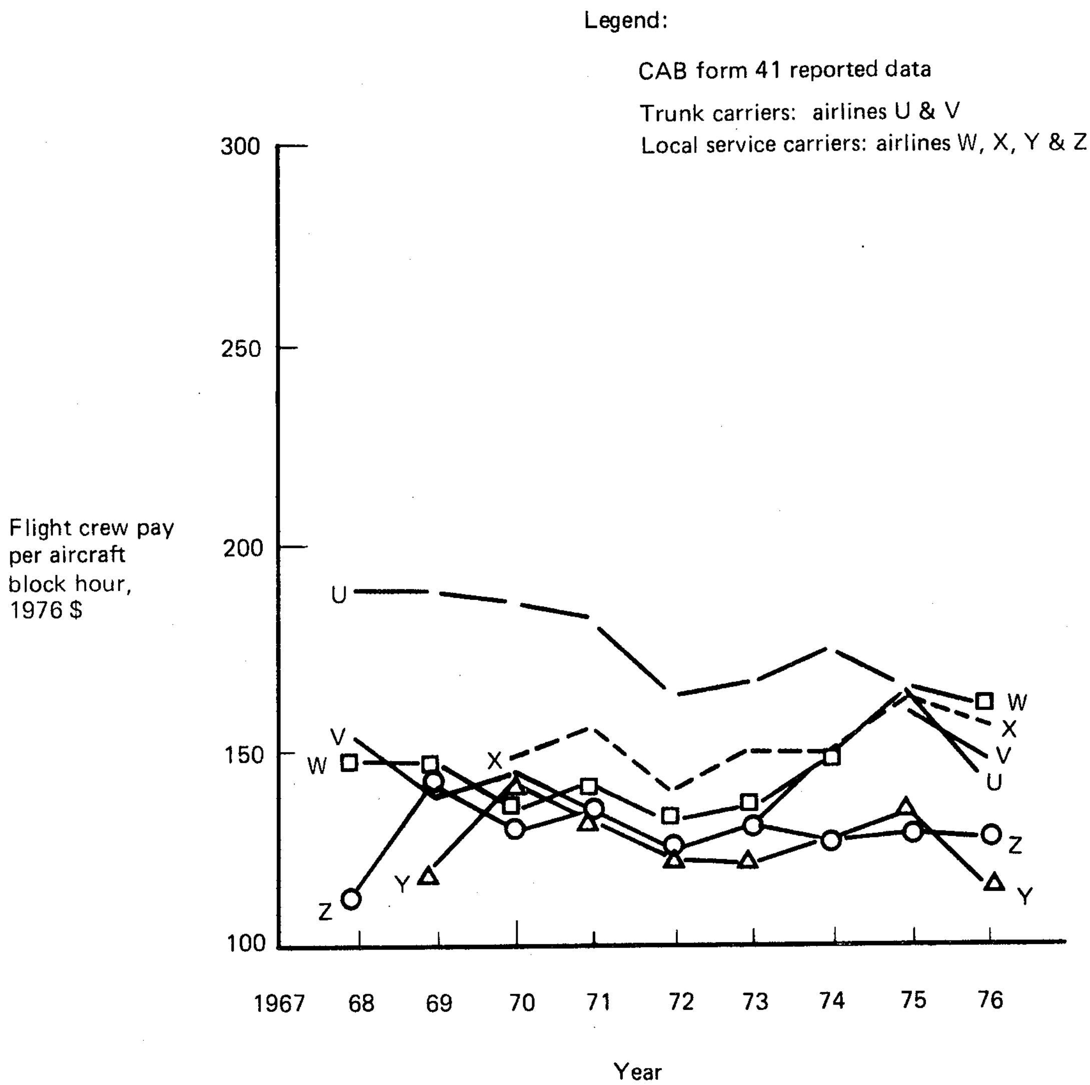

Figure 25.—Comparison of Flight Crew Pay for Douglas DC9-30 Series Aircraft in U.S. Domestic Operation

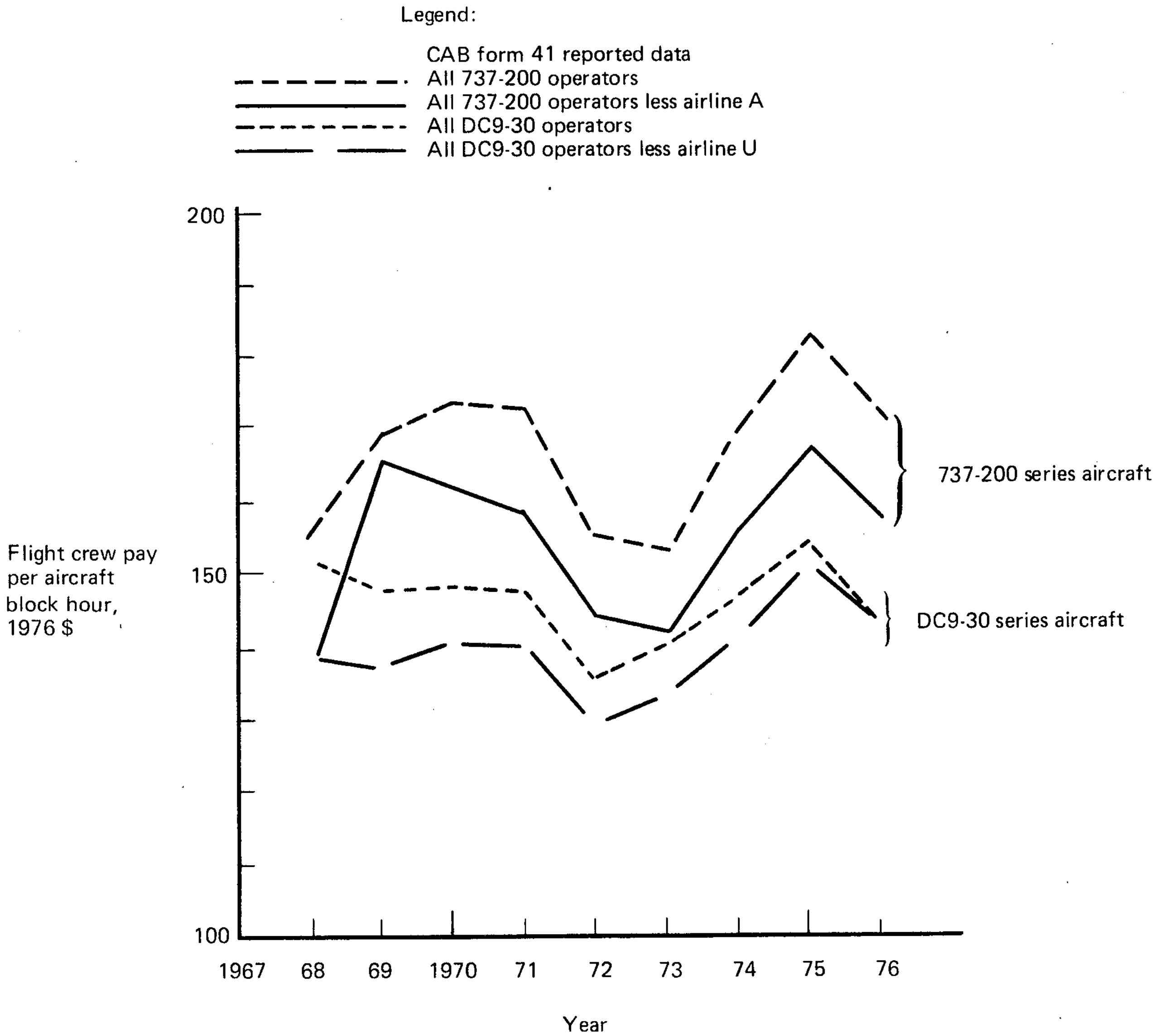

Figure 26.—Comparison Between Annual Mean Flight Crew Pay for Boeing 737 and DC9 Aircraft in U.S. Domestic Operation

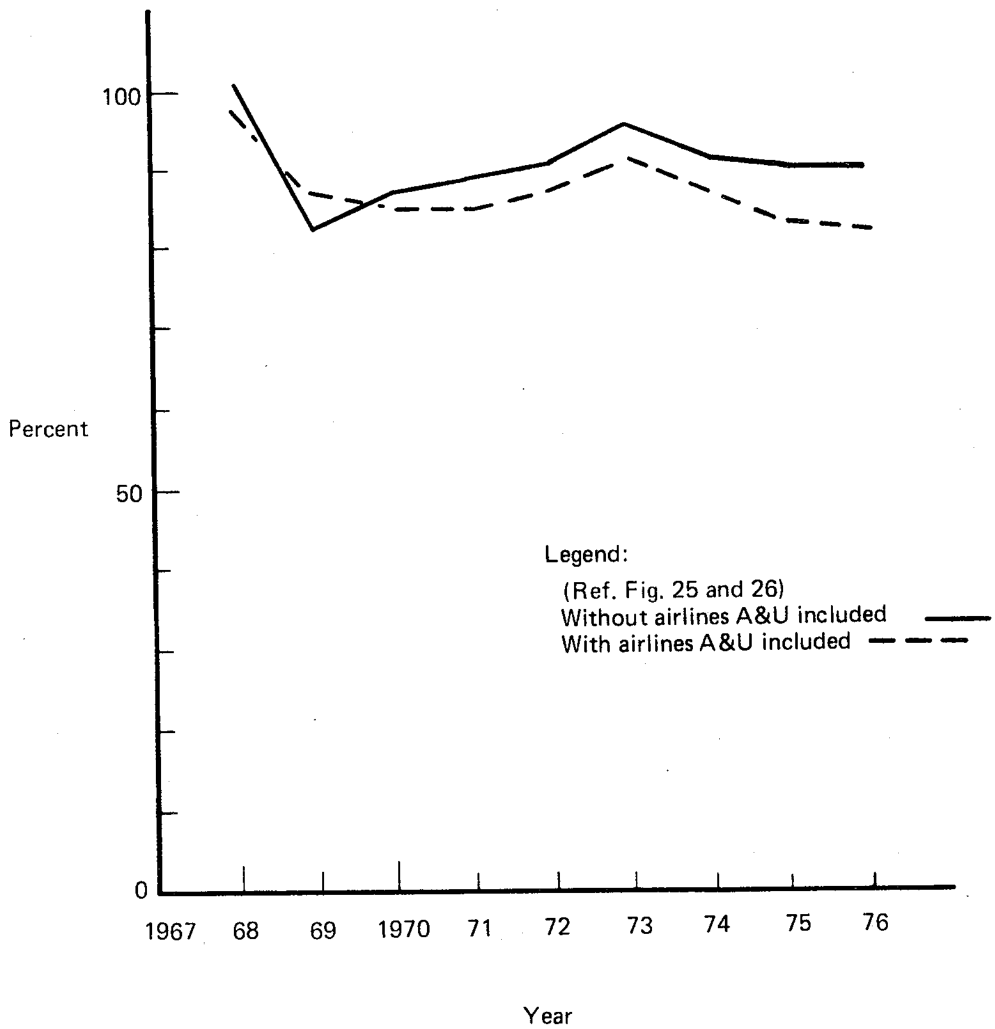

Figure 27.—Annual Mean DC9-30 Series Aircraft Flight Crew Pay Per Block Hour Expressed As a Percentage of Annual Mean 737-200 Flight Crew Pay Per Block Hour for U.S. Domestic Operators

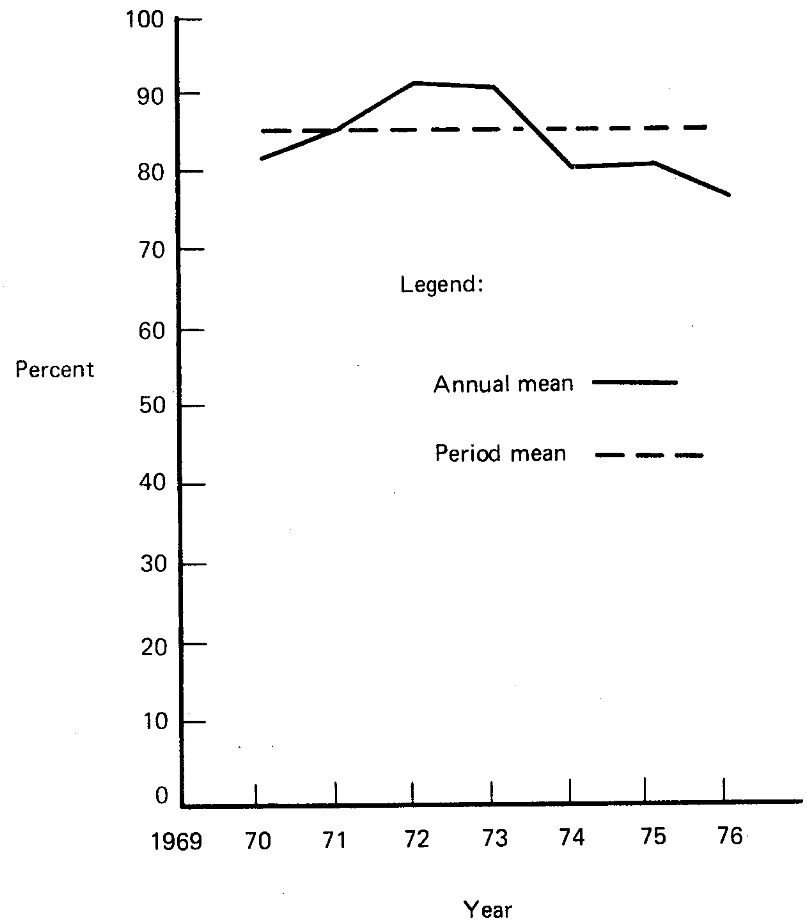

Figure 28.—Annual Mean 737-200 Series Aircraft Two-Man Flight Crew Pay Per Block Hour Expressed As a Percentage of 737-200 Series Aircraft Three-Man Flight Crew Pay Per Block Hour for U.S. Domestic Operators

Improvements in technology that would also result in lighter aircraft (without a change in aircraft size) through the extensive use of composites and other lightweight materials and aerodynamic design break throughs, could also provide impetus to a reduction in flight crew pay, provided the current basic rule of their pay being a function of aircraft weight remains unchanged during all future union negotiations. However, American and other airlines recognize that the use of gross weight as a measure of productivity is both complex and somewhat controversial. Nevertheless, at this time, it is felt that gross weight will continue to be used as one of the main determinants of cockpit crew pay for subsonic airplanes for the foreseeable future. This will probably hold true even for major technological gains in weight reduction (e.g. through the use of composite materials), and most certainly for comparing different airplane types embodying similar technology. Other elements of technological change could serve to offset some or all of the cost savings associated with reduced weight and cockpit workload. For example, the implied (or inferred) new hazard associated with liquid hydrogen fueled aircraft could introduce a new cost parameter into crew pay considerations that might negate the design and structural weight savings.

4.4.3 FLIGHT ATTENDANTS PAY

Although flight attendant costs are currently considered part of an airline's indirect operating cost in the CAB system of accounts, flight attendants are a necessity on most passenger carrying aircraft. The minimum complement of flight attendants required on a flight is legislated by FAR 121.391 and is based on aircraft seating capacity (see table 6). Therefore, it is possible to fly an aircraft in a normal configuration (i.e., a 15/85% mix of first class and coach passengers), with a given number of flight attendants, and the number may have to be increased if the aircraft interior is changed to higher density seating configuration. In addition, a desired higher level of cabin service, competitive pressures, etc. can also result in the provision of more flight attendants on a flight than required by the FAA minimums.

Flight attendant compensation is on a monthly basis without regard for the minimum number of hours flown. There is a contract negotiated maximum number of flying hours per month, and any service beyond that number receives additional compensation on an hourly basis.

Flight attendant compensation (both monthly basic and hourly additional) is on the basis of length of service. This longevity pay reaches a plateau after 12 years of service.

As a result of the liberalization of flight attendant employment requirements, the average tenure of flight attendants at American Airlines has increased from under 3 years in 1968 to nearly 7 years in 1976. Figures 29 and 30 show the distribution of head count by years of service and average tenure by calendar year respectively for American Airlines flight attendants. On the basis of these data, and on the assumption there will be minimal attrition in the flight attendant ranks, the average service of AA flight attendants could reach 10 years in May, 1982, and 12 years in May, 1987.

The cost of providing flight attendants on aircraft can be expected to increase as a result of their increasing seniority of service. It is anticipated future union negotiations will result in both a significant increase in the basic monthly rate and a reduction in the number of hours to be worked each month before overtime eligibility is reached. Recent contract settlements reached and those currently being negotiated by regional carriers, suggests the impact of flight attendant expense will become even more significant in the immediate and distant future.

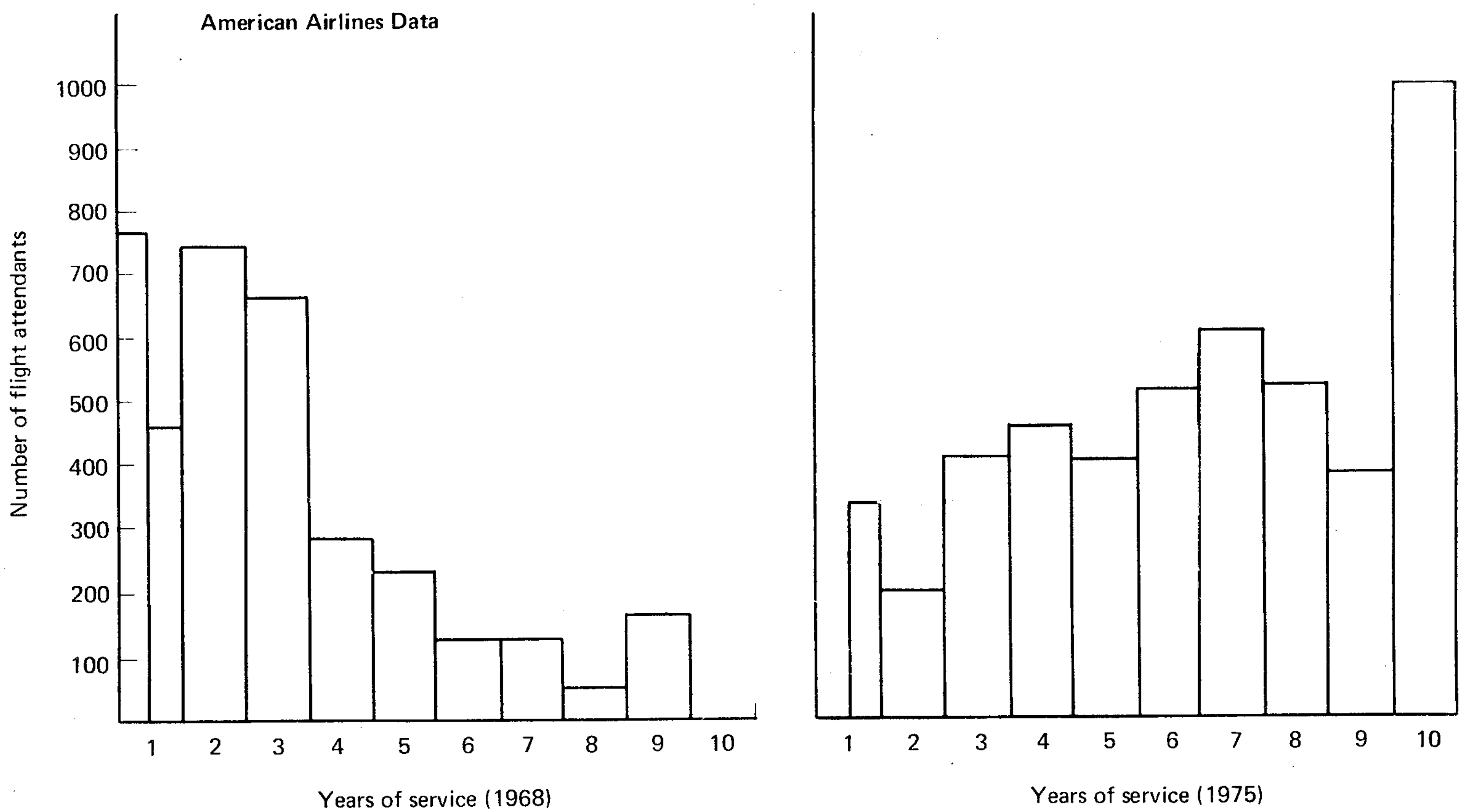

Figure 29.—Distribution of Flight Attendants By Years of Service

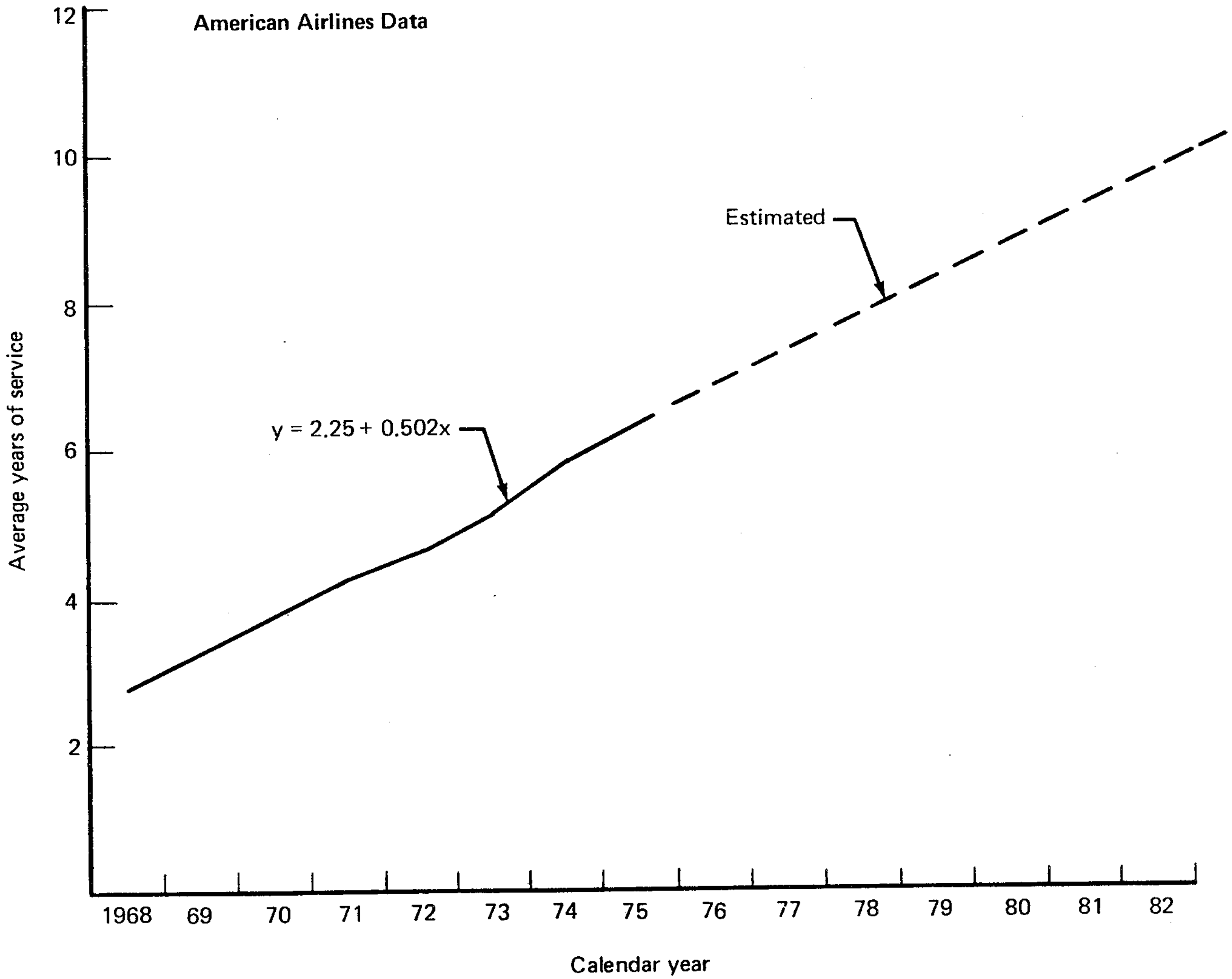

Figure 30.—Actual and Projected Average Years of Service For Flight Attendants By Calendar Year

Table 6.—FAR Minimum Flight Attendant Requirements

Aircraft	Seating capacity	Minimum FAA requirements	Normal AA Assignment	Maximum AA Assignment
B-727/100	*Up to 98 incl.	3	3	5
B-727/200	*Up to 131 incl.	3	3	5
B-707/123	*Up to 142 incl.	3	4	5
B-707/323	*Up to 150 incl.	3	4	5
B-707/323	*From 151 to 175 incl.	4	4	5
DC-10	From 201 to 250 incl.	5	8	10
DC-10	From 251 to 300 incl.	6	8	10
DC-10	From 301 to 350 incl.	7	8	10
B-747	From 301 to 350 incl.	7	10	14
B-747	*From 351 to 388 incl.	8	10	14
B-747	*From 389 to 445 incl.	9	10	14

*This maximum figure represents 5% increase above the demonstrated evacuation in accordance with FAR 121.291 (a) (2) otherwise maximum limited by FAR 121.391.

As the basic premise on the need for flight attendants is now safety oriented, programs which are directed toward improving aircraft safety and facilitating the egress of passengers (including those handicapped) from an aircraft in the event of an accident, could assist airlines in reducing the minimum FAA required complement of attendants on each flight.

Development programs for passenger service items that are directed toward reducing the workload of flight attendants (microwave ovens, automated bar service, etc.) could also have a similar beneficial effect.

In an endeavor to avoid the expense of unnecessary staffing of certain low load factor flights, airlines have introduced a variable manning technique. Flight attendants are assigned to flights on the basis of historical load factor and the degree of passenger service to be provided, always complying with FAR minimums. In addition, should reservations for a specific flight show a load factor significantly higher than that normally encountered, it is not uncommon for standby flight attendant(s) to be assigned to the flight.

Figures 31 and 32 express the recent average flight attendant crew complement direct pay as a function of the number of aircraft seats and as a function of flight length. Note that this direct pay includes salaries only and does not include indirect costs for fringe benefits or route expenses.

The relationship between flight attendant crew pay and aircraft gross weight was also explored in the hopes flight deck crew and flight attendant crew pay could utilize the same base line data in the D.O.C. model. Unfortunately, these items did not correlate as well as the parameters eventually chosen.

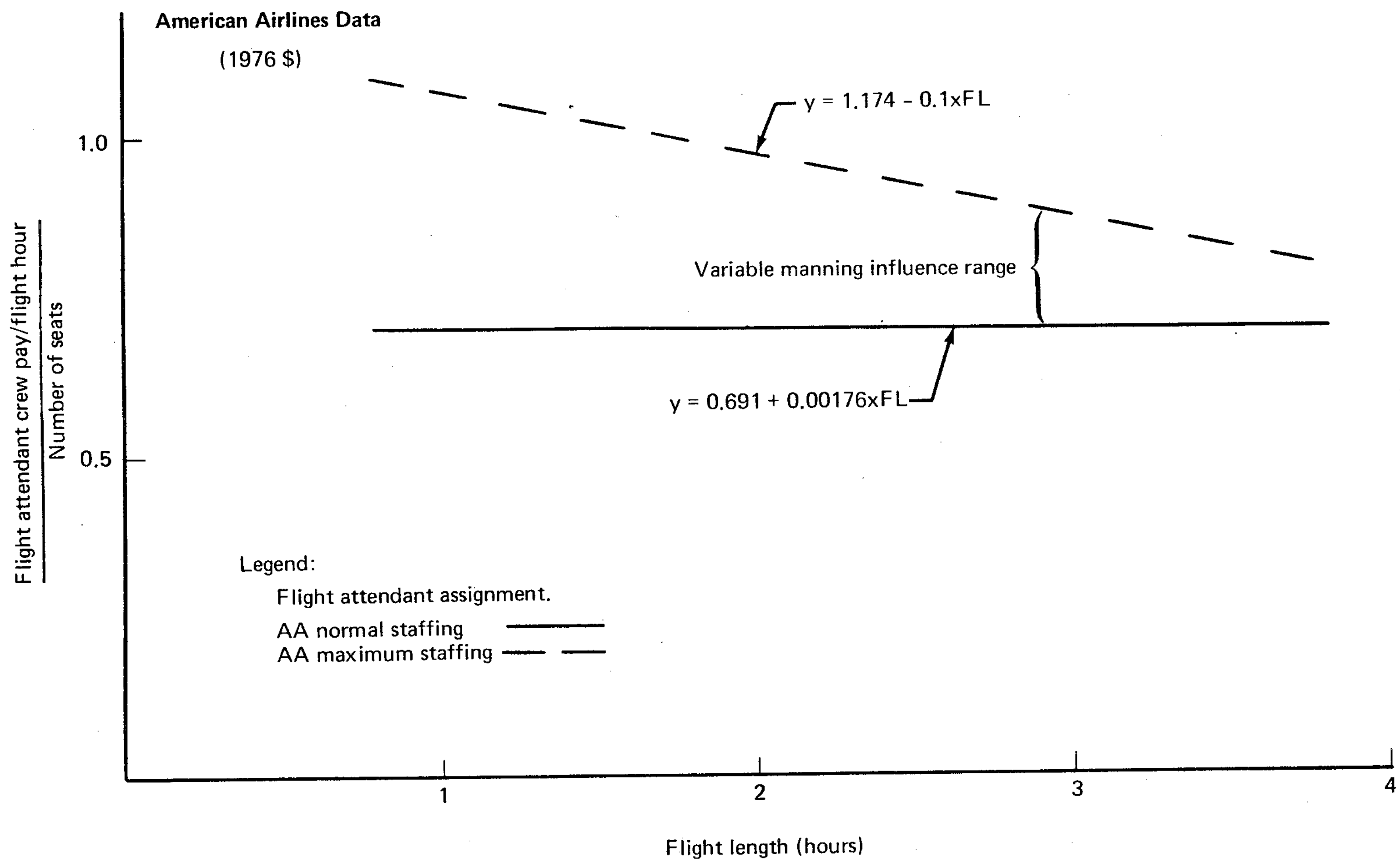

Figure 31.—Flight Attendant Crew Pay Normalized By the Number of Seats Expressed As a Function of Flight Length

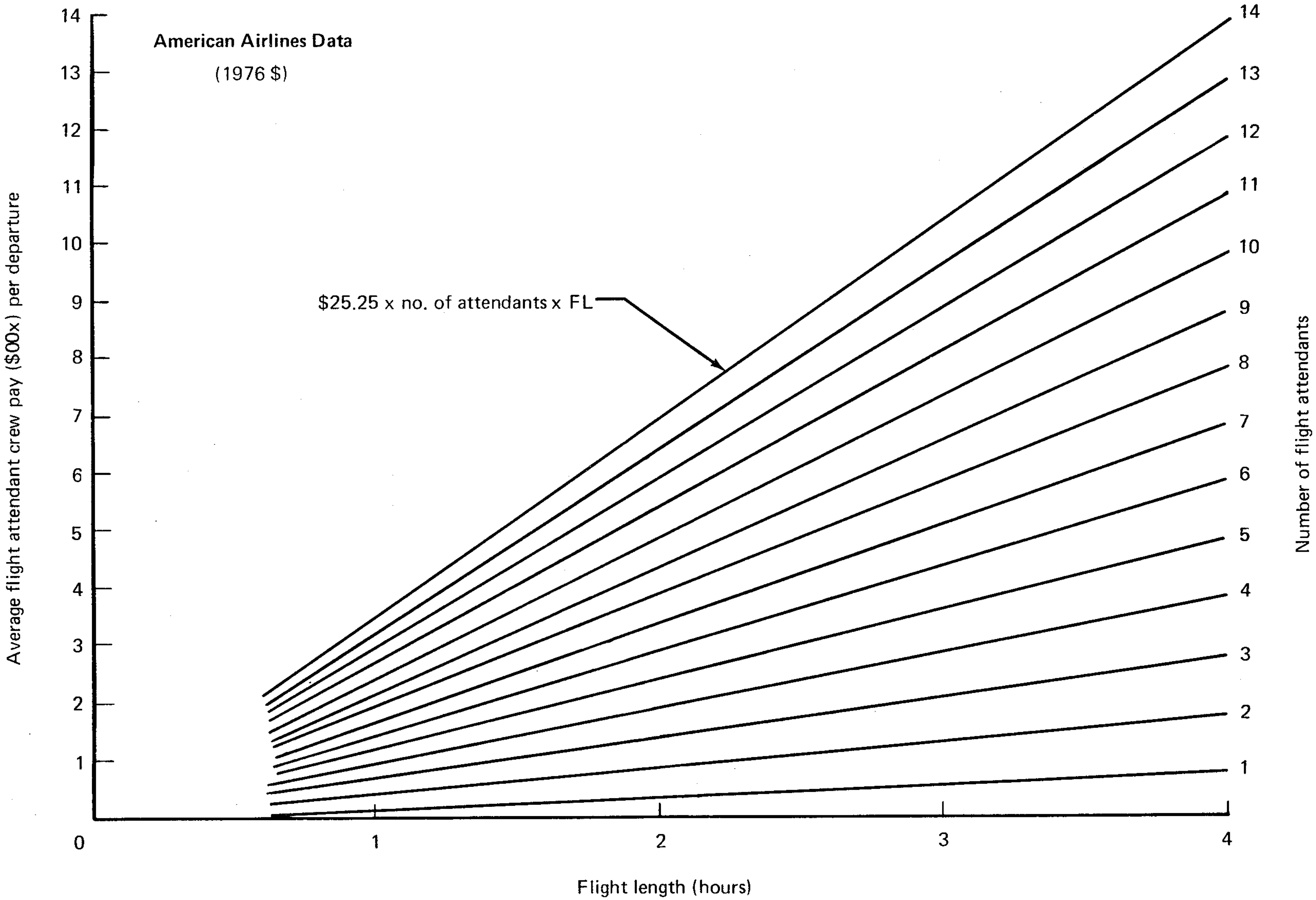

Figure 32.—Distribution of Flight Attendant Crew Pay Per Departure As a Function of Flight Length

4.4.4 FUEL EXPENSE

The highest item of expense facing the airline industry today is the price of aviation kerosene. Air Transport Association member airlines consume in excess of 34 billion liters of aviation kerosene per year or 94.6 million per day. In 1976, average domestic aviation kerosene prices varied from 6.6 cents to 8.5 cents per liter, while overseas the price for a liter of aviation kerosene averaged 9.8 cents.

The price and amount of fuel consumed annually by American Airlines since commencement of jet operations is shown on figure 33. The distribution of fuel by aircraft type is shown on figure 34.

Prior to the oil embargo by the Organization of Petroleum Exporting Countries (OPEC) and the resulting price escalation, the U.S. Domestic price of aviation kerosene had stabilized for nearly 10 years at the 1976 dollar equivalent of 5 cents per liter.

Since the price of fuel is so strongly influenced by domestic and world political climate as well as the rate of oil resources depletion, the methodology is designed to accept the prevailing price of fuel at the time of use.

The relationship of fuel to airplane design features is relatively well understood and can be readily assessed once the performance of the aircraft, the payload, the price of fuel and a set of mission rules have been defined. The data needed to assess the effects on fuel consumption when design features are changed may be derived from theoretical analysis, experimental wind tunnel testing, or production flight tests, and later proven by inservice experience from airline operation.

In order to develop a first order appreciation of the variations in fuel expense with design characteristics, statistics on various inservice aircraft were examined to relate seats, range, and weight, for a series of specific designs.

First it was assumed that the operating empty weight of the aircraft was made up of some items which were seat count related and other weights which were maximum takeoff weight related. Table 7 reflects the grouping of weights used for the regression lines of figures 35 and 36.

The relationships of design range, seat capacity, operating empty weight and fuel consumption are shown by the following derivation using the Breguet equation:

$$R = \frac{L}{D} \times \frac{V}{TSFC} \times \ln \frac{W_1}{W_2}$$

where

R = range

$\frac{L}{D}$ = lift-drag ratio

V = cruise speed (true air speed—TAS)

$TSFC$ = thrust specific fuel consumption

W_1 = initial gross weight

W_2 = final weight

$RF = \frac{L}{D} \times \frac{V}{C}$ = range factor

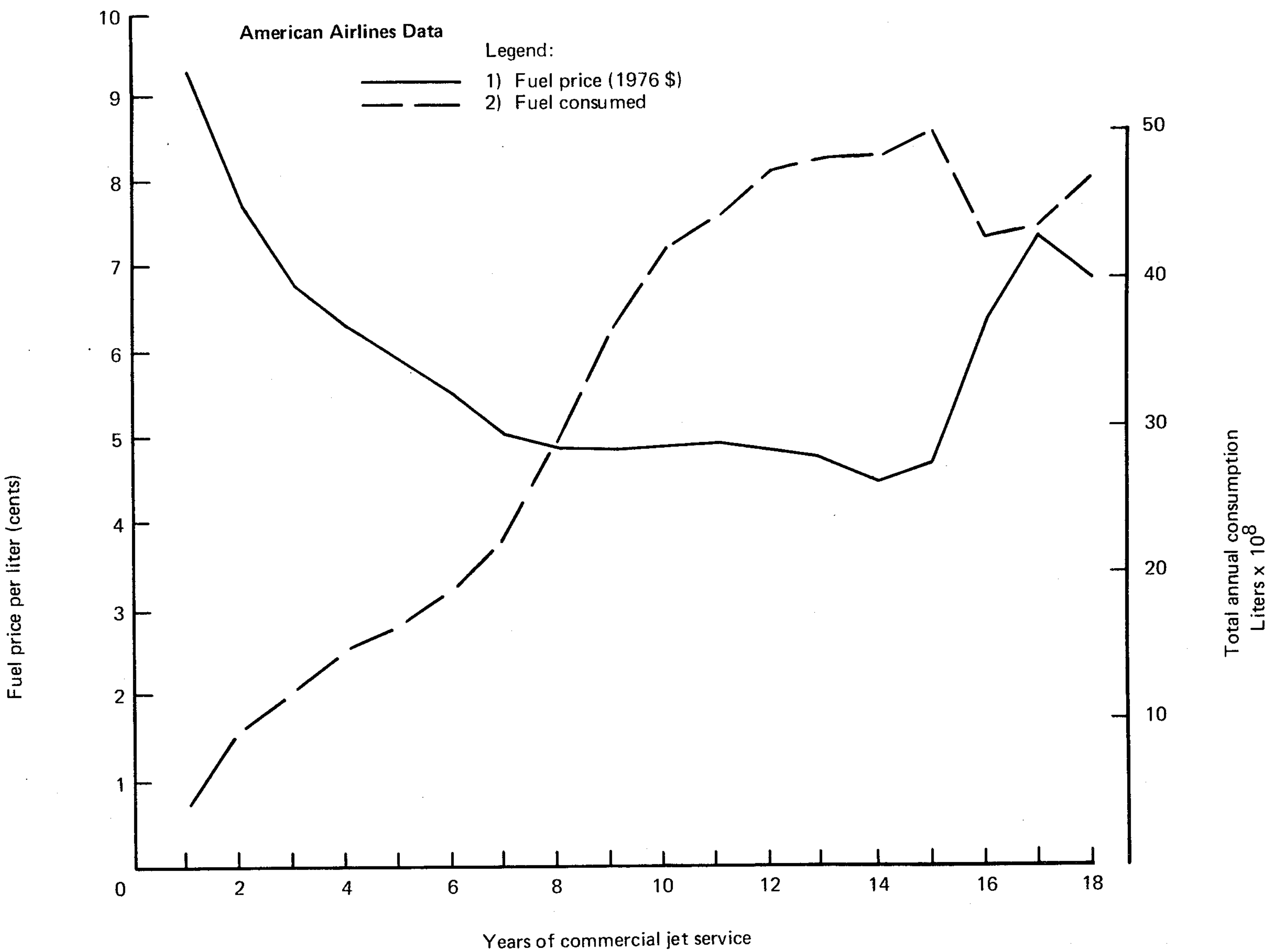

Figure 33.—Aviation Kerosene Price and Consumption

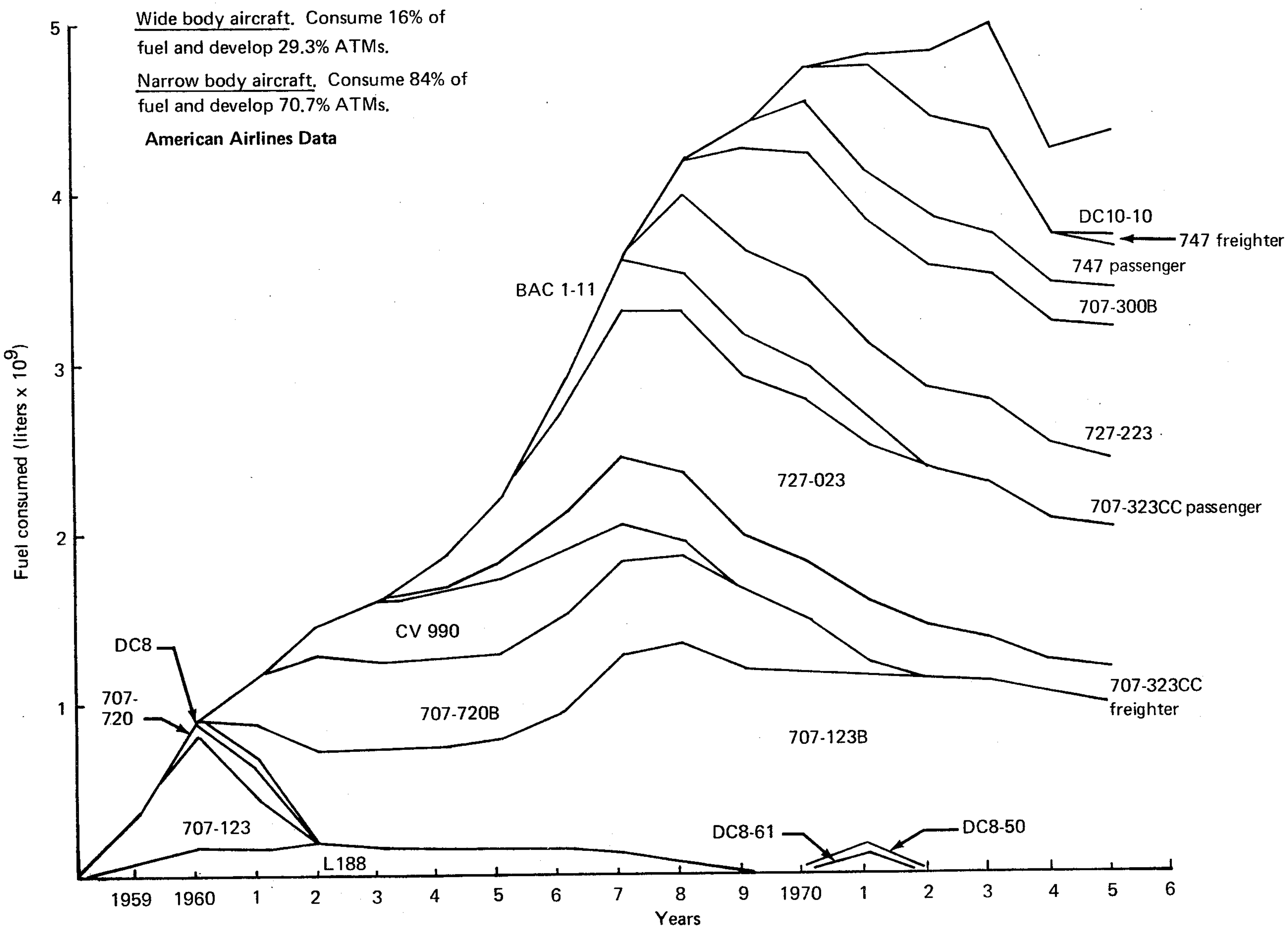

Figure 34.—Distribution of Fuel Consumption By Aircraft Type

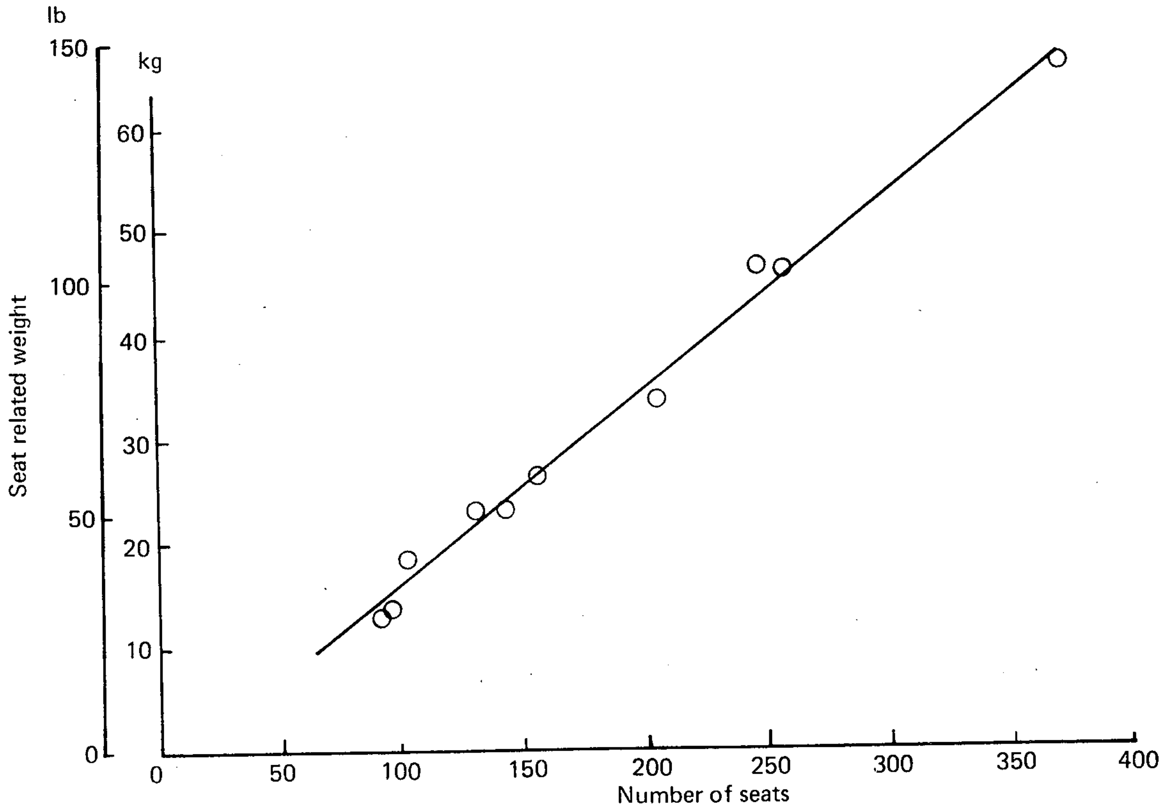

Figure 35.—Seats Related Weights

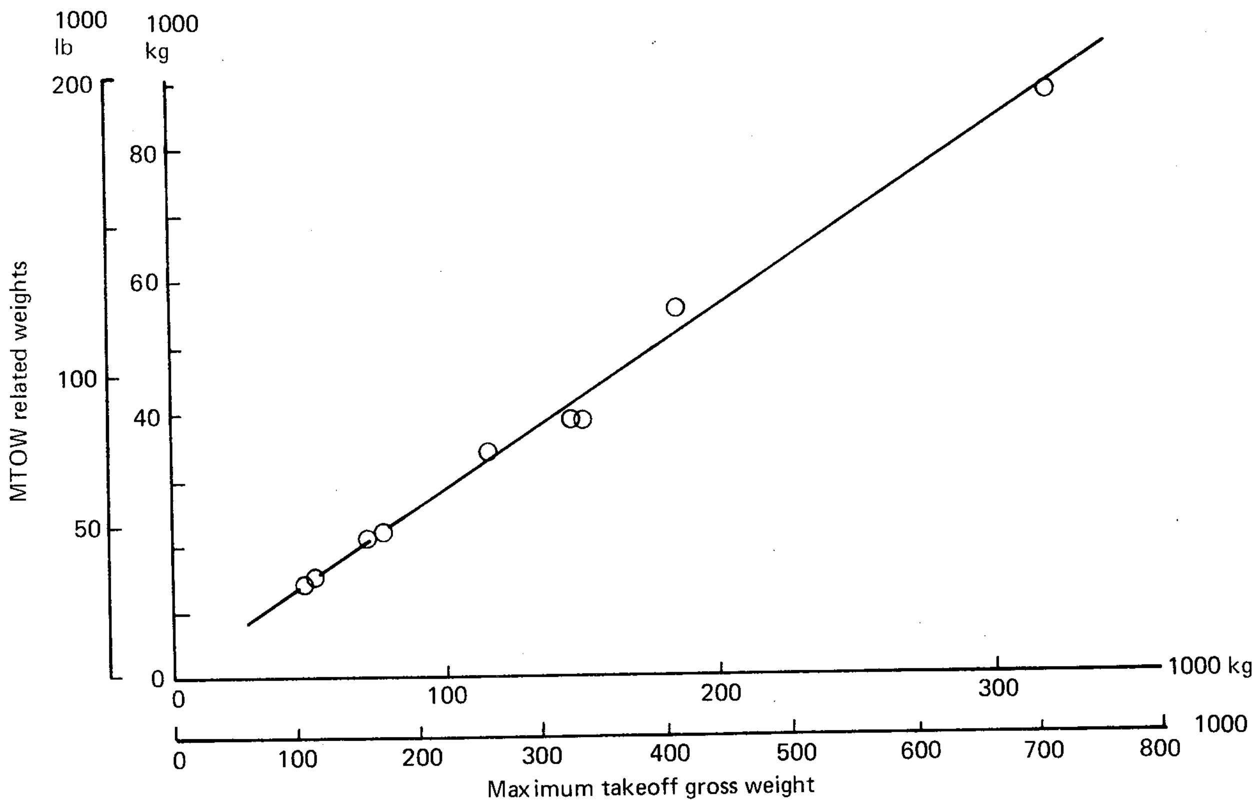

Figure 36.—Maximum Takeoff Gross Weight Related Weights

Table 7.—Airplane Weight Relationships

Seat count related weight items	Maximum weight related weights
Body	Wing
Instruments	Horizontal tail
Pneumatics	Vertical tail
Electrical	Main landing gear
Electronics	Nose landing gear
Flight provisions	Nacelle and strut
Passenger accommodations	Propulsion system group
Cargo handling	Surface controls
Emergency equipment	Hydraulics
Air conditioning	Anti-icing
Auxiliary power unit	
Exterior paint	
Options	
Standard and operational items	

Operating empty weight can be considered a function of payload (seats) and takeoff gross weight.

$$\text{OEW} = \text{A} \times \text{seats} \times \text{B} \times \text{TOGW} + \text{C}$$

Where the coefficients A, B, and C are taken from the empirical relationships shown in figures 35 and 36.

$$\text{OEW} = 186.18 \times \text{seats} + .2756\ \text{TOGW} - 1898.28$$

The takeoff gross weight function is found next.

$$R = RF \ln \frac{K_1 W_T}{W_L} \quad \text{where } K_1 = .98 \text{ and accounts for the effect of climb}$$

and descent in the mission profile so that W_1 = TOGW (W_T) and W_2 = landing weight (W_L).

The ratio of landing weight plus reserve fuel (ATA domestic rules) to OEW plus payload can be approximated by substituting 1852 km in the Breguet equation

$$1852 = RF \ln \frac{W_L}{\text{OEW} + \text{PL}}$$

$$\frac{W_L}{\text{OEW} + \text{PL}} = e^{\frac{1852}{R}}$$

This factor is empirical but approximates the calculated reserves for a broad range of current technology airplanes. Landing weight can then be expressed as:

$$W_L = (OEW + 93 \times S)\left(e^{\frac{1852}{RF}}\right)$$ where S = seats and 93 = passenger weight in kg

where $\left(e^{\frac{1852}{RF}}\right)$ accounts for the fuel reserve requirement.

$$\frac{R}{RF} = \ln \frac{K_1 W_T}{W_L} \qquad \therefore \; e^{\frac{R}{RF}} = \frac{K_1 W_T}{W_L}$$

then $W_T = (OEW + 93 \times S)\left(e^{\frac{1852}{RF}}\right)\left(\frac{e^{\frac{R}{RF}}}{K_1}\right)$

substituting K_e for $\left(e^{\frac{1852}{RF}}\right)\left(\frac{e^{\frac{R}{RF}}}{K_1}\right)$

$$OEW = 186.18 \times S + .2756\ (OEW + 93 \times S)\ K_e - 1898.28$$

$$\frac{OEW}{SEATS} = \frac{186.18 + .2756 \times 93 \times K_e - 1898.28}{1 - .2756\, K_e}$$

This provided the basis for the carpet plot of figure 37.

Regression analysis curves of the cruise range factor against design range are shown on figure 38, and indicate a general dependency on engine by-pass ratio (BPR) and/or body width. The turbofan trend lines are superimposed on the OEW-per-seat carpet plot in figure 39.

To establish the fuel burned or block fuel function, a similar approach was used for varying mission and design ranges.

$$R = RF \ln \frac{K_1 (W_L + W_F)}{W_L}$$

W_F = block fuel

W_R = reserve fuel

$$W_L = (OEW + 93 \times S)\left(e^{\frac{1852}{RF}}\right)$$

$$W_R = (OEW + 93 \times S)\left(e^{\frac{1852}{RF}} - 1\right)$$

$$W_F = W_T\left(1 - \frac{K_1}{e^{\frac{R}{RF}}}\right)$$

$$\text{Fuel aboard} = W_F + W_R$$

An example of block fuel efficiency in terms of seat miles per liter based on the above correlation of existing airplane parameters is shown on figure 40.

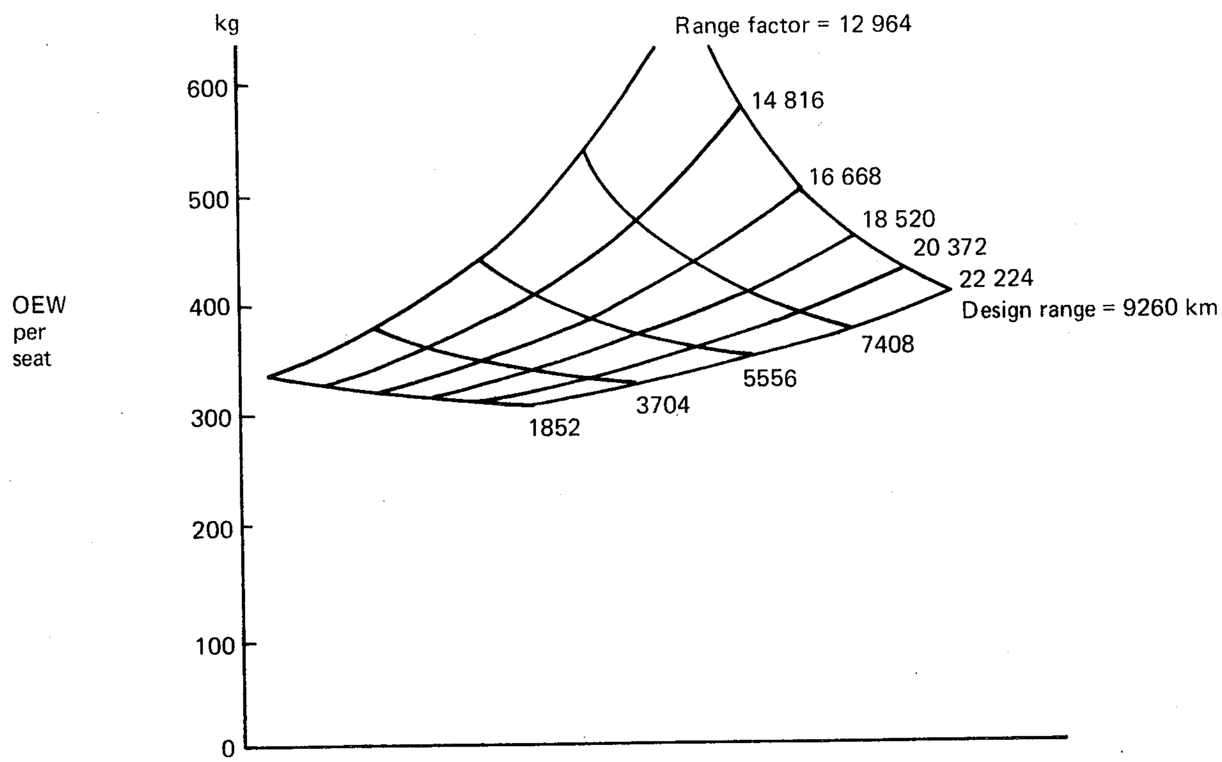

Figure 37.—Operating Empty Weight Per Seat

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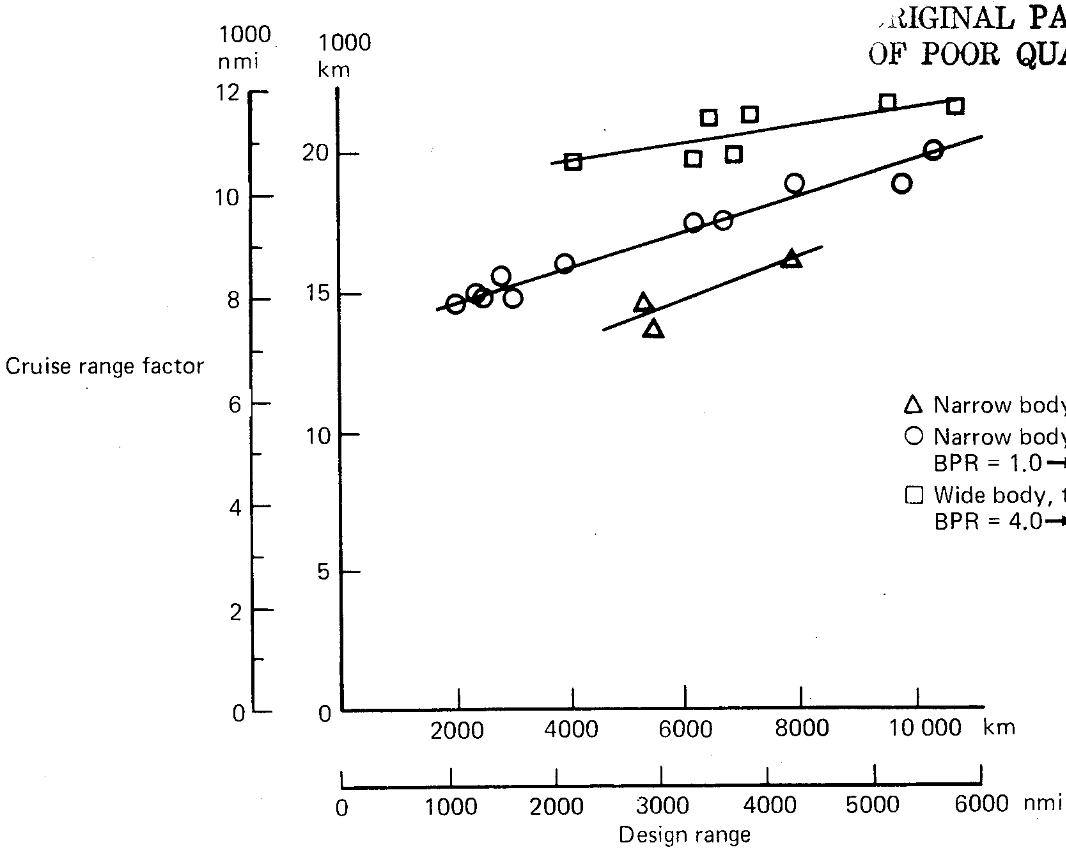

Figure 38.—Cruise Range Factor Trends

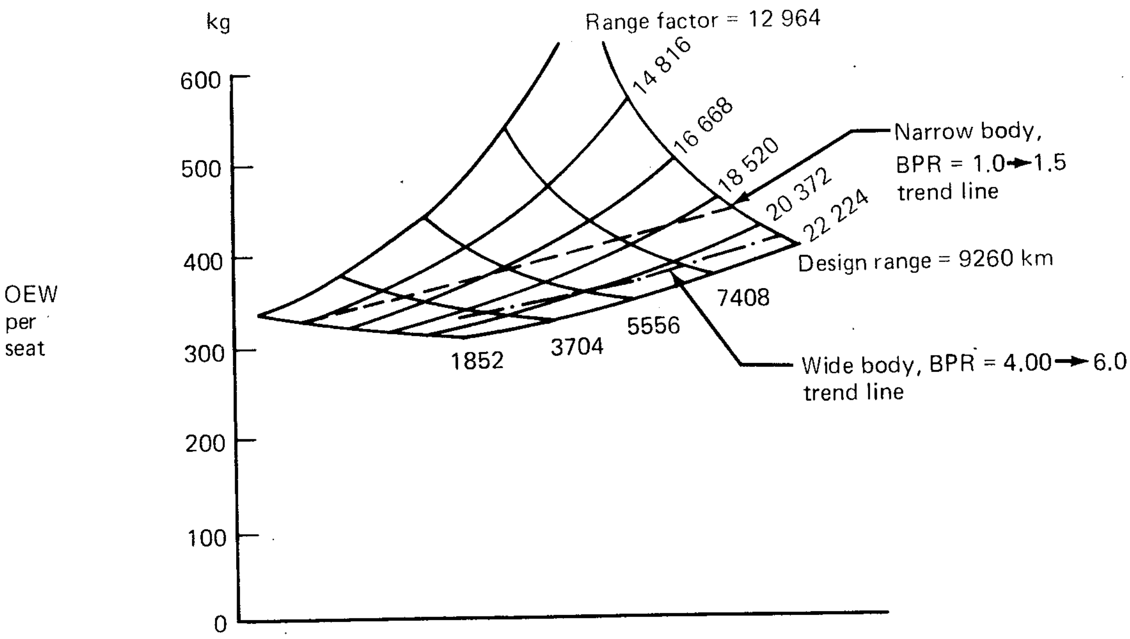

Figure 39.—Operating Empty Weight Trends

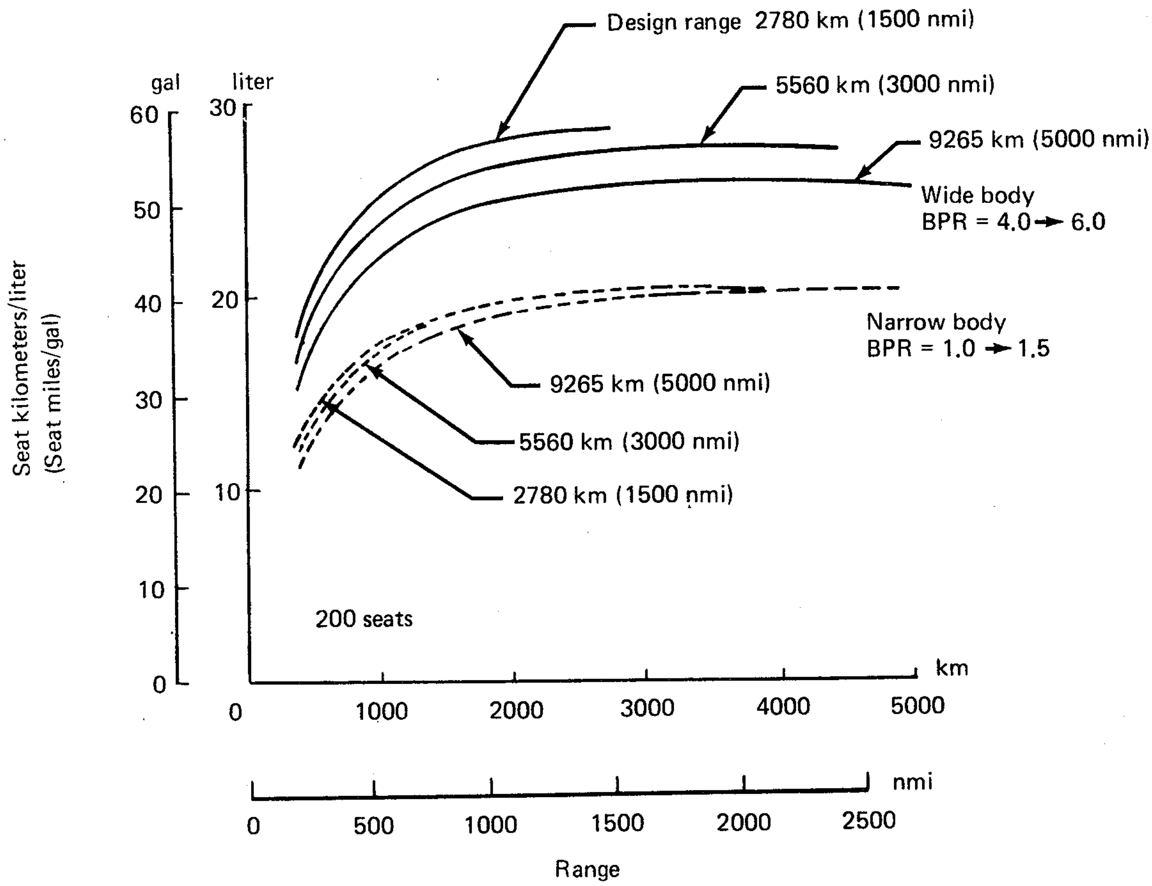

Figure 40.—Effect of Design Range on Fuel Mileage

Data from which the level of fuel consumption is defined for those phases of development up to and including production flight test are generally derived under closely controlled test conditions. Likewise, the configuration and condition of the airplane are also usually well defined and controlled in order to demonstrate the best possible fuel mileage for the airplane. Therefore, when comparing different airplanes with similar levels of development, reasonable assurance exists that the comparisons will be valid. Experience has shown that fuel consumption characteristics for different airplane types may vary considerably in service from factory-new levels. Additionally, a given airplane type can demonstrate large differences in fuel consumption characteristics from one airplane to another owing to different maintenance practices, route structures, aircraft age, and operating practices. These inservice fuel burn variations range from almost no deterioration for a well maintained, near new airplane, to as much as six or seven percent deterioration.

As a result of the wide variations in fuel consumption characteristics which occur in service, no attempt is made in this report to make a detailed study of inservice fuel burn levels. However, as noted earlier and as may be seen from the following discussion, it is important that, when comparing different airplanes, the correct fuel burn level be used for each type, including the effect of deteriorated inservice levels judged to apply to manufacturer demonstrated fuel consumption levels.

From the idea to production, aircraft go through phases of development which may be categorized as follows. The initial phase consists of defining mission criteria—payload and range, and investigations of configurations which will satisfy mission requirements. Theoretical analysis of these configurations/engine combinations is used to develop preliminary performance data.

The second phase begins with the selection of the best configurations analyzed in phase one. Now the theoretical data is confirmed or revised by testing the configurations in the wind tunnel. Refinements in design are continuously tested until the best configuration is selected. Documentation of best estimates of performance data is begun, and these data become the basis for guaranteeing the performance of the aircraft to prospective customers.

The third phase begins with the flight test program. Part of the flight test program is devoted to testing for actual drag and specific fuel consumption. These data are used to update the performance documentation and now become the basis for guarantee compliance. The third phase is a continuous one of testing configuration and engine improvements. The performance will be revised whenever the flight test program shows sufficient changes in the data to warrant revision.

Once the basic characteristics of a design have been established, any change in weight, drag, or specific fuel consumption will result in a corresponding increase or decrease in fuel burn, which can be readily estimated. However, any such change is likely to alter the basic performance from the design point. It is only during the early configuration definition phase that the designer has the option of recycling the design to optimize performance for the design mission. As an example, suppose that the designers of a medium-range airliner, such as that defined in table 8, decide to add equipment weighing 454 kgs to the fuselage. This will require an increase in structural weight. If the original design mission capability is to be maintained, the airplane must be resized, with a resulting increase in wing area, engine thrust, and fuel consumption. The 454 kgs of additional equipment will actually result in an OEW increase of approximately 680 kgs, and a takeoff gross weight increase of about 907 kgs (see figure 41). The sensitivity of these parameters will increase with increasing design range because of the compounding effect of the fuel required to carry the additional weight over a greater distance.

Table 8.—Sensitivity Study—Baseline Airplane

Seats Design range	175 5334 km
Engines Number/type SLST—newtons By-pass ratio Weight per engine—kg	 4/turbofan 82 880 5.0 1095
TOGW—kg OEW—kg Body weight—kg Wing weight—kg	116 755 63 004 13 181 12 574
Wing area—m^2 Fuselage length—m	197 43.5
TOFL (sea level, 90°F)—m Cruise mach no. Initial cruise altitude—m Approach speed—m/sec	2256 0.84 10 058 63

The same logic applies to any savings in weight, either by eliminating equipment or reducing the structural weight, with a resultant reduction in airplane weights, size, and engine thrust. Similarly, a change in drag or specific fuel consumption will result in a resizing of the airplane to meet the original design mission requirements.

These effects can be illustrated by examining an earlier internal Boeing parametric study. This parametric study utilized the same methods used in a previous NASA report, *Study of the Application of Advanced Technologies to Long-Range Transport Aircraft*, contract NAS1-10703. (See Volume 1—*Advanced Transport Technology Final Results*, May, 1972, by The Boeing Company). However, while the NASA study addressed the problem of mach .90 to .98 airplanes, the internal Boeing study examined a mach .84 design. A baseline airplane was defined, with characteristics as shown in table 8. Using the computer design program, variations were made in body weight, wing weight, engine weight, drag, and specific fuel consumption, with the airplane being resized to maintain the same optimized performance. Figures 41 through 45 show the sensitivity of airframe weight, OEW, TOGW, engine SLST, and block fuel to these variations for the baseline airplane defined in table 8. The block fuel sensitivity is for an 1852 km mission. For any new design the effect of variations in technology would be determined by construction of trades similar to those shown on figures 41 through 45.

4.4.5 AIRCRAFT SERVICING

Aircraft servicing expense involves cleaning the aircraft, filling the seat pockets with appropriate materials, preparing the galleys, checking the logs, fueling, etc. The fuel costs were covered in section 4.3.2 and are excluded from the costs discussed here. The rest of the servicing costs are directly related to the aircraft and its operation even though presently excluded from the conventional CAB Direct Operating Cost categories. The magnitude and distribution of these costs for a major airline can be assessed from that of American Airlines shown in figure 46.

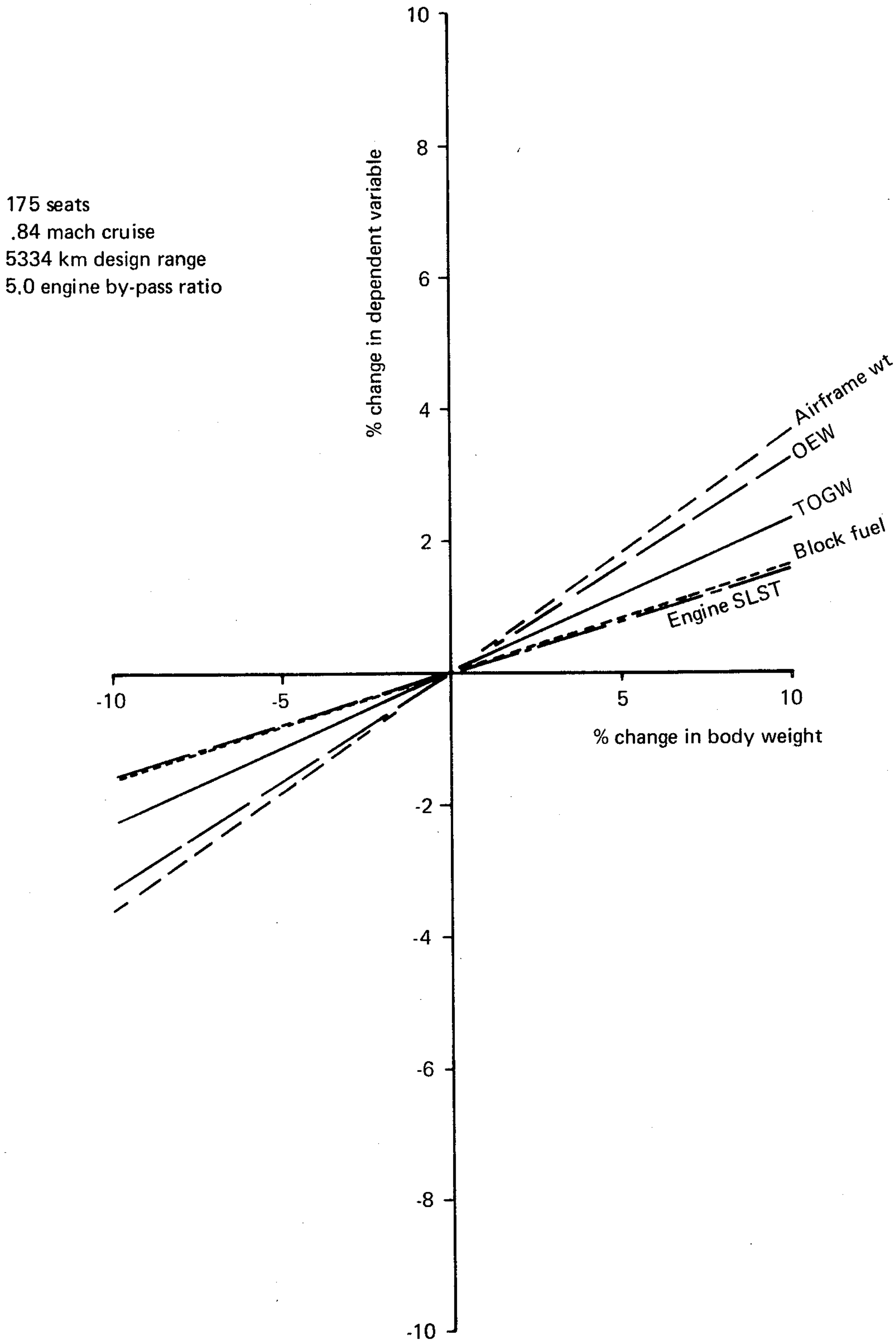

Figure 41.—Sensitivity Study—Effect of Change in Body Weight

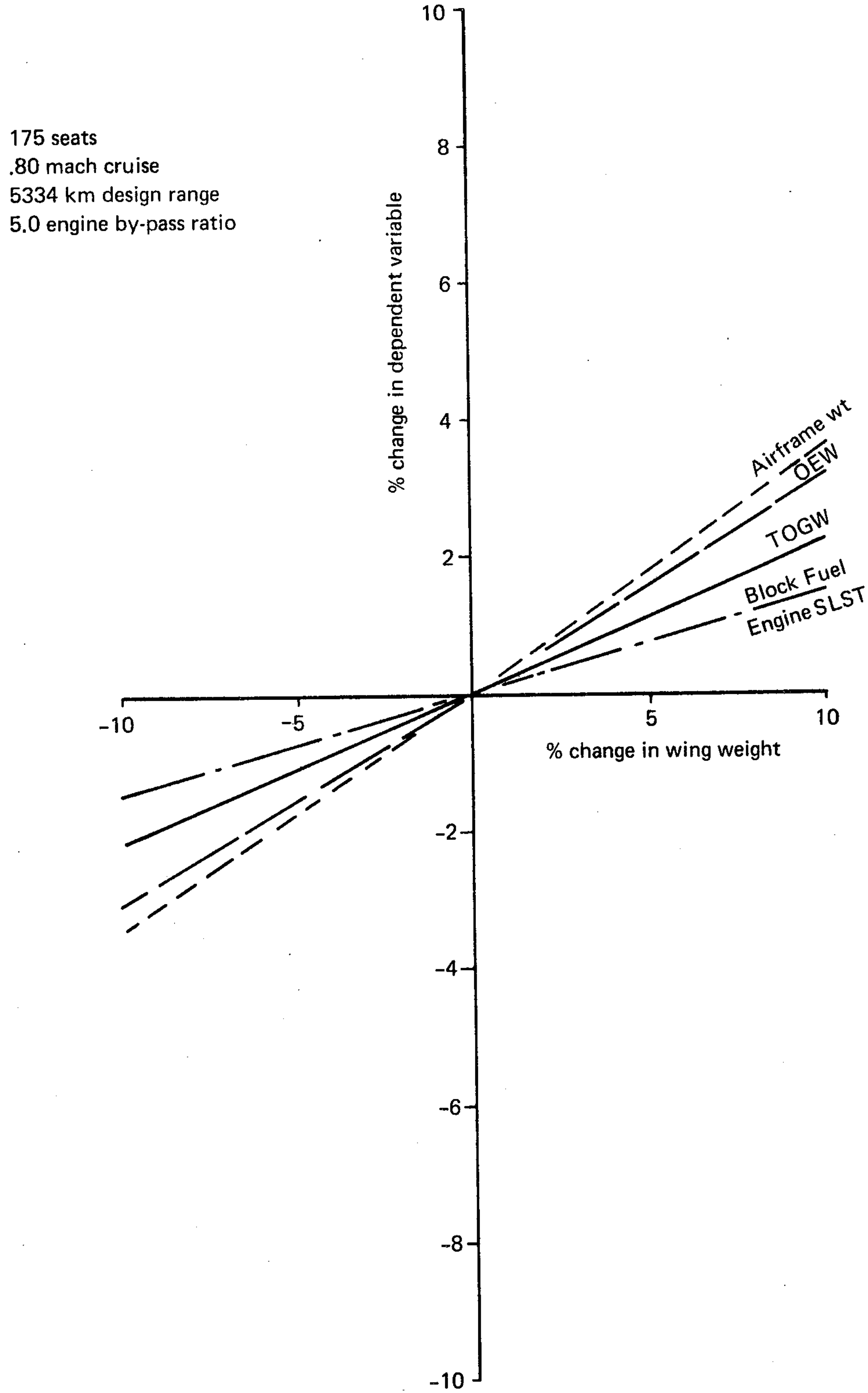

Figure 42.—Sensitivity Study–Effect of Change in Wing Weight

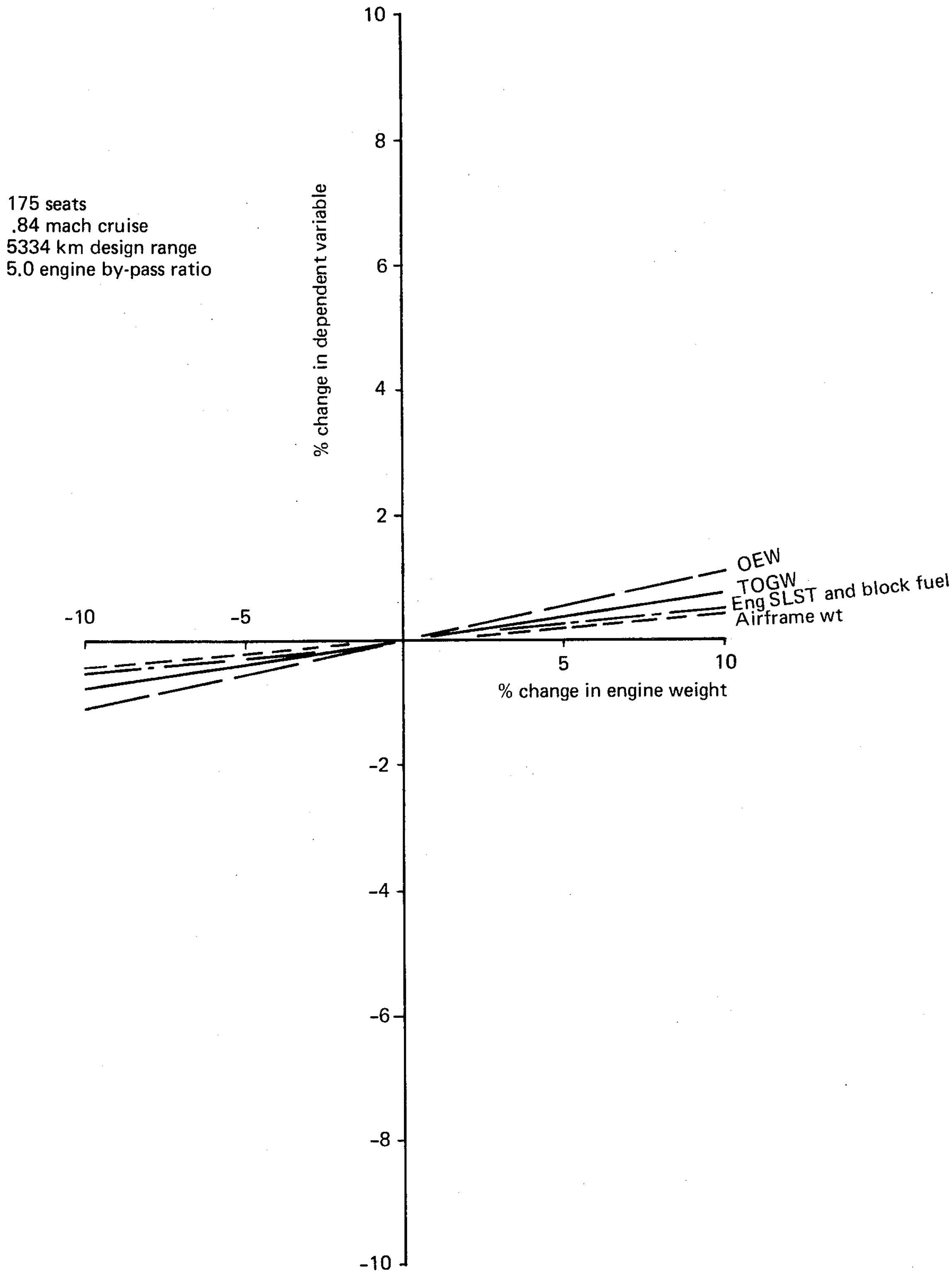

Figure 43.—Sensitivity Study—Effect of Change in Engine Weight

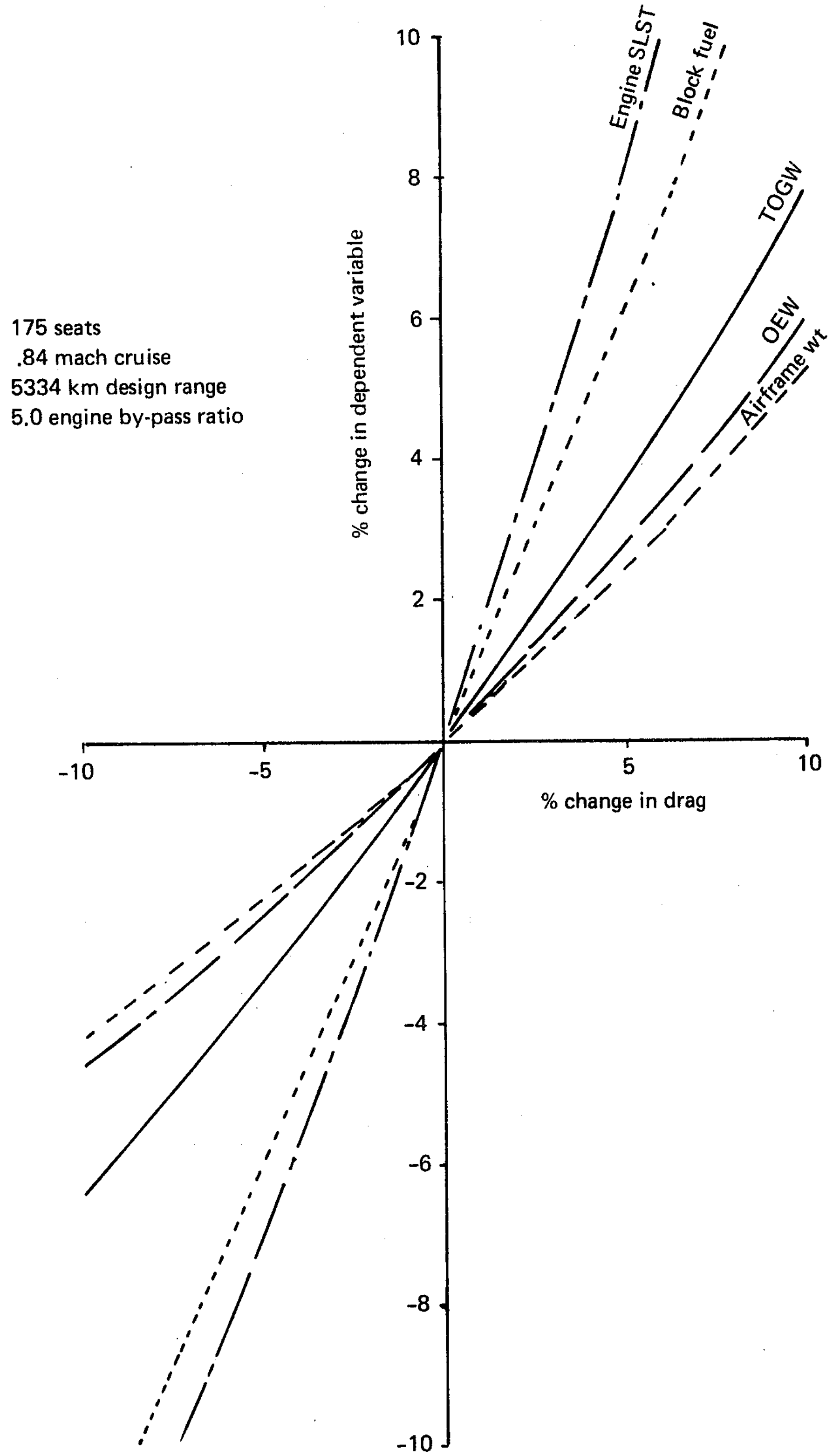

Figure 44.—Sensitivity Study—Effect of Change in Drag

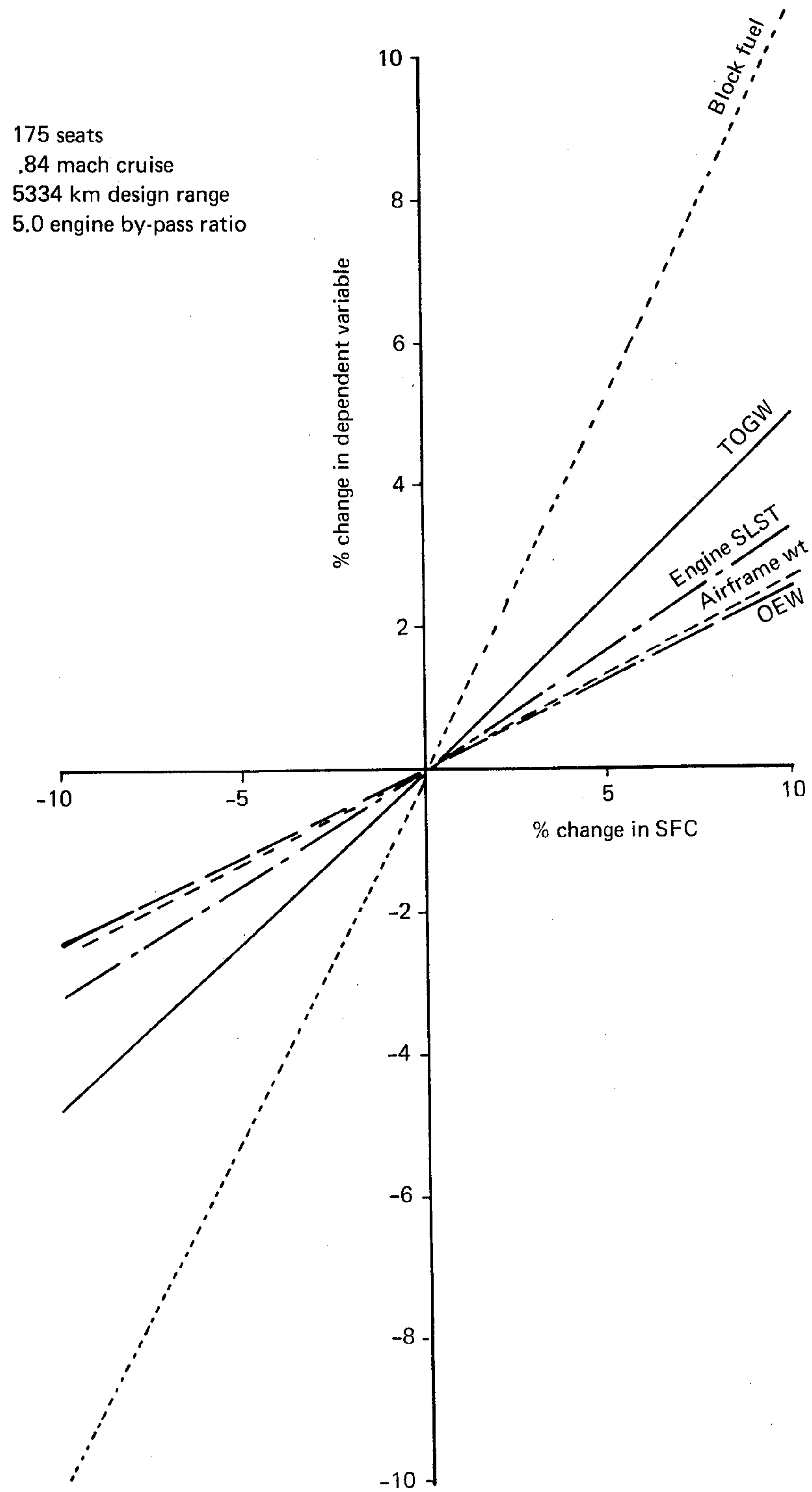

Figure 45.—Sensitivity Study—Effect of Change in Specific Fuel Consumption

American Airlines annual average for years 1974 and 1975

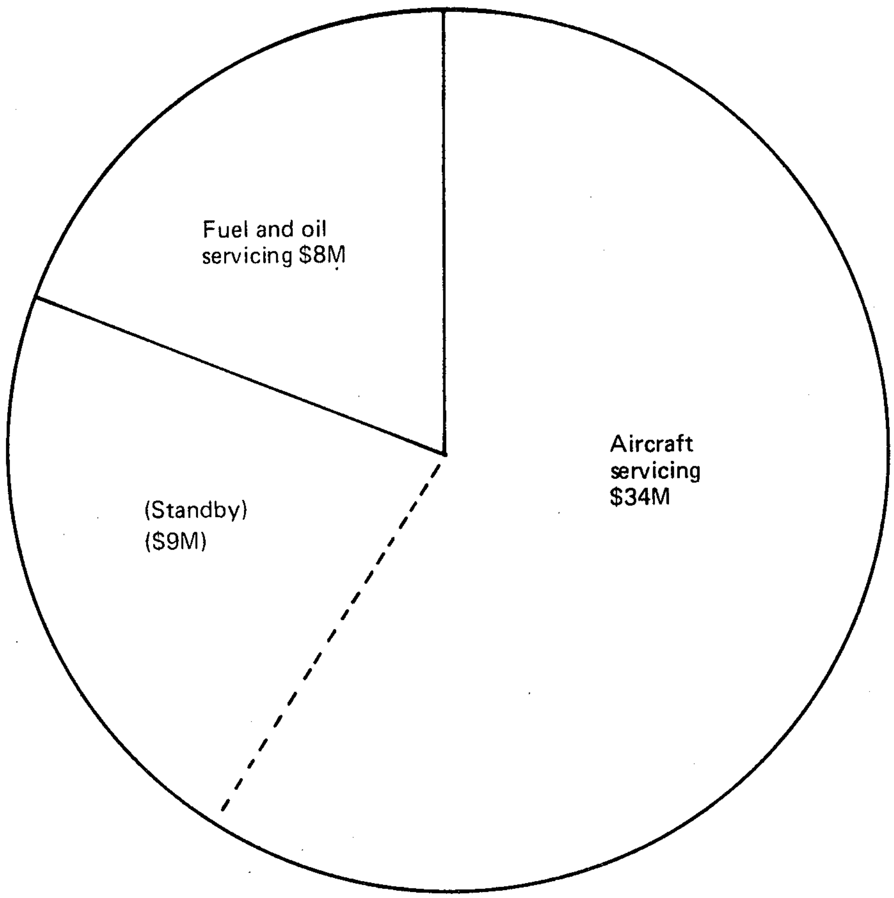

Figure 46.—Aircraft Servicing Expense (Fully Allocated Labor)

The servicing expense, essentially a labor charge, is a function of aircraft size and is influenced by the level of service desired, competitive pressures and the area of operation; viz, intercontinental, domestic, or local service. Aircraft operating on high service (e.g., intercontinental) routes require more man-hours for cabin servicing and preparation than those same aircraft operating lower level (e.g., night coach and/or local) services. The trip cost for aircraft servicing as a function of aircraft size and type of operation, as typified by U.S. intercontinental trunk, domestic trunk, and local service operations has been developed by Boeing from industry experience data and is shown in figure 47. Average annual aircraft servicing expenses per trip for American Airlines aircraft have been plotted on figure 47 for comparative purposes. The influence of a disproportionate amount of short haul load building stages adversely affects the average servicing cost per trip for 707-323B and 707-323C aircraft. However, DC-10 and 747 aircraft, which are operated predominantly on 2 to 7 hour flight segments and experience a higher level of cabin service, are closer to the line for aircraft in domestic trunk medium and long range operations.

4.4.6 MAINTENANCE COST

4.4.6.1 Introduction

The expense associated with the direct maintenance of an aircraft and its associated equipment can be relegated to two major categories: airframe systems, and propulsion systems. Propulsion systems maintenance costs were the subject of a previous NASA study, reference 1 (NASA CR 134645, "Economic Effects of Propulsion System Technology on Existing and Future Transport Aircraft," by G. Philip Sallee, July 1974). This section will deal only with airframe material and labor costs representative of jet transports in service today. A short form equation for airframe maintenance costs is also provided on table 14 of this document.

The Air Transport Association of America (ATA) several years ago established a set of airframe and powerplant system codes to provide a uniform means of reporting and exchanging information within the airline industry. These codes are defined in detail by reference 14 (ATA Specification 100) and are listed in table 9.

In addition to the standard ATA Specification 100 codes, two additional codes were designed for the purposes of this study to correspond to the American Airlines method of data reporting. Code 99 was used to designate airframe maintenance items which could not be assigned to a specific system; these items consisted primarily of labor expended on routine inspections. Code 50 designates structural maintenance which could not be identified and assigned to a particular system or structure.

A parametric method of defining costs for the individual airframe systems as defined by ATA Specification 100 will be developed. This method can then be used as a basis for generalized comparison of various airplanes, and as an aid in determining the magnitude of the effects particular changes to an airplane can have. Since it is a generalized method, it cannot be used to accurately define actual costs for a particular airplane model or airline situation; however, it does provide a relative comparison when evaluating specific variances in aircraft systems and configurations.

Due to the data sources used, this method will represent costs for a mature fleet of airplanes operated by an airline doing all work inhouse with the parameters selected reflecting current technology. However, since the analysis was made on an ATA Specification 100 system basis as opposed to the more

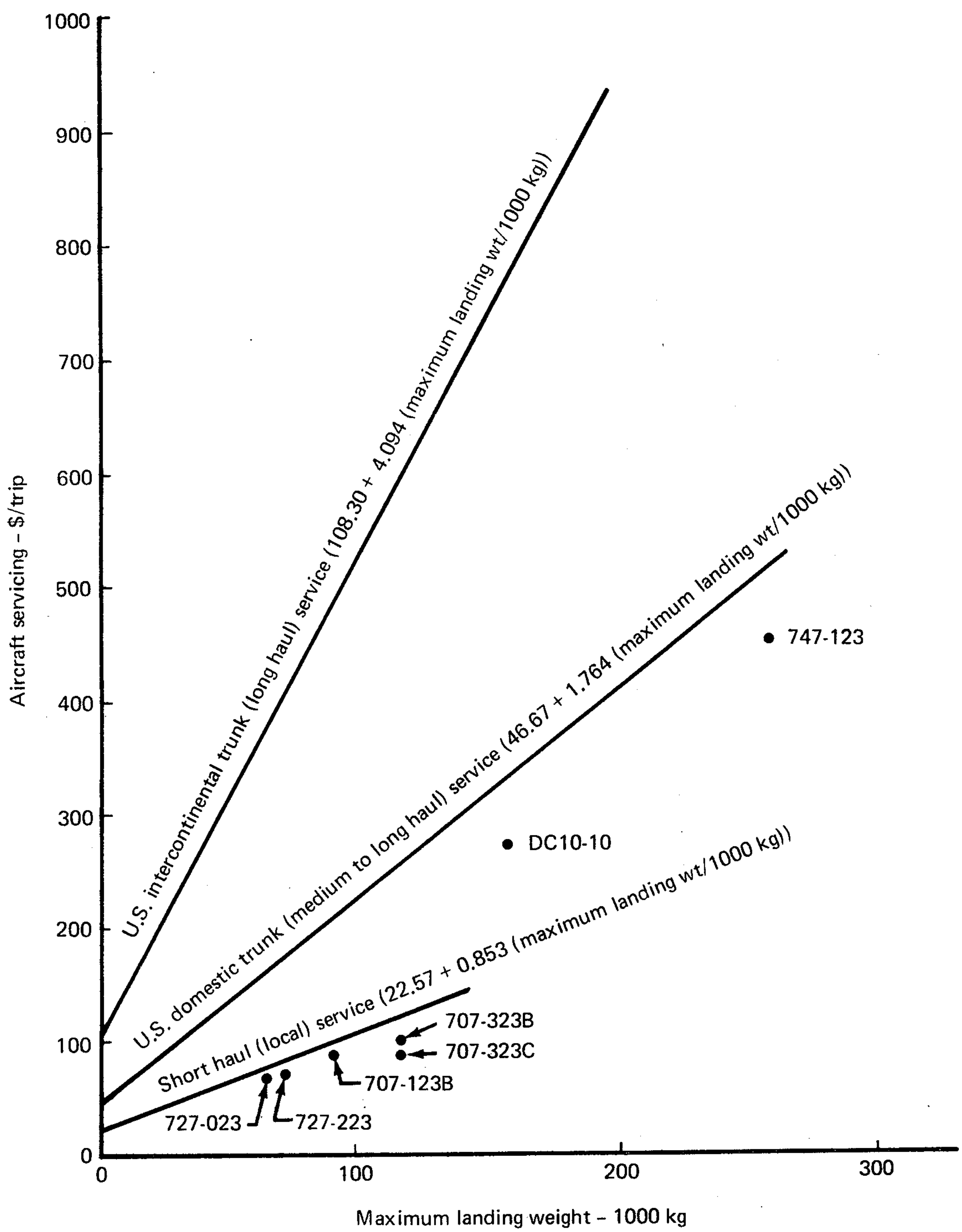

Figure 47.—Aircraft Servicing

general approach of the previous 1967 ATA formula, it can be used to show the effect of specific technological changes as will be discussed.

The general approach used to define costs by the ATA Specification 100 system was to make all necessary adjustments to the base data sources and then normalize the resulting costs to a 2.5 hours flight for all airplane models. After removing flight length as a major variable, correlation analyses were then used to determine the best parameters for generalizing costs for each ATA system. Example calculations for unique airplanes are included to demonstrate the methods used.

4.4.6.2 Airline Maintenance Cost Accounting Methods

Airlines have developed methods to collect maintenance costs for two purposes.

The primary purpose is to provide the airlines' management with an awareness of the distribution of airline equipment maintenance expenses. The secondary purpose is to conform with the Civil Aeronautics Board requirements as outlined in Part 241 of the CAB Economic Regulations relating to a Uniform System of Accounts and Reports for Certificated Air Carriers. Copies of sections 11 and 12 pertaining to airline operating and maintenance expense reporting are presented in Appendix III.

The methods developed by the airlines to fulfill these two basic requirements are as varied as the number of airlines, and no two airlines use either the same methods, procedures or rule interpretation. The end result is an array of data which requires extensive, in-depth study to be of value for any evaluation or comparative purpose.

As a result of the variety of airline maintenance accounting methods, the following will apply specifically to those methods used by American Airlines; the end product in terms of the distribution of maintenance expenses can be considered as fairly representative for an airline of its size. However, the means of identifying and collating the various maintenance expenses is not necessarily representative of that used elsewhere in the airline industry.

The methods used to collect propulsion system maintenance expense were previously addressed in reference 1.

The aircraft systems and associated components are more unique than the propulsion system components. It is normal for routine inspections and repairs to be performed on the aircraft systems and components at a number of locations and for major inspections and repairs to also be carried out at facilities other than those provided at the main base. The degree of skills necessary to perform a given task and the availability of those skills at certain locations form the basis for the decision on where a given inspection, modification and/or repair (routine or special) will be performed.

To facilitate the collation of labor, material and repair service charges related to the work performed by line maintenance on an aircraft during service, and the processing of either the aircraft or a component through a repair facility, the following accounting system has been developed.

Each task or collection of specific tasks are detailed on a work card either computerized or manually written. Each card is assigned a cost collection number and all labor and material charges are collected by either operation number or line on the card.

Routine and nonroutine aircraft inspections are assigned a permanent cost collection number for either each task or a collection of tasks depending on the degree of skill level and time required to perform such tasks. For example, a specific task requiring a high degree of skill and/or special tooling (e.g., borescoping an engine) may have a single cost collection number. A number of routine inspections, similar to those performed on a walkaround inspection, may also be collected under a single collection number. All labor and material charges, including those of any local repairs found necessary as a result of the inspections, are charged against the assigned cost collection number(s).

Similarly, cost collection numbers are assigned to cover the expenditure of labor and materials for modifications performed on the aircraft systems and components at either line maintenance station or during the processing of the component through a major repair facility during routine or nonroutine repair/refurbishment.

When an aircraft, aircraft system, or component is routed to the main repair facility for inspection and repair activity, each task or collection of tasks are similarly assigned cost collection numbers for the collation of incurred charges.

Each component and support shop is also identified by a code in order that an awareness of the area in which the expense was generated and the component on which that expense was incurred is retained.

All labor, material, in-house repair and outside service charges are collected and retained independently under the various shop cost collection numbers and charged against either the aircraft, system, or component charge code numbers as determined necessary.

Items forwarded to outside vendors for repair are processed under a repair order number and charges are accrued in the outside services ledger against each particular aircraft system or component.

Computerized accounting methods have assisted enormously in acquiring, retaining and distributing this data in various formats in order that either management or a particular user can be aware of major expense items and initiate corrective action programs as necessary.

In collating charges against a given aircraft system or component, the labor expense element is charged as it occurs. The expendable materials (e.g., cleaning fluids, lubricants, etc.) are usually issued in bulk to the user and charged against the user at that point. Therefore, charges for expendable material can only be averaged against the number of activities performed by the user versus the dollar value of the expendable material issued to him.

Repairable items are charged with the repairs performed. In the event that the part reaches a point where it is no longer economically repairable, it is then scrapped and the charge registered against the aircraft system and/or component in which it had last been installed.

The determination of economic repairability is usually made on the basis of repair cost and anticipated life versus new part cost. However, in certain instances, such as long lead time items, repair cost may be secondary to the financial impact on the airline's operation that could arise by extended component out of service time.

The basic problem in the current accounting method is that the labor, material and outside service charges are collected through the year and measured against the total aircraft hours currently being flown by that type during the review period rather than the hours that each individual aircraft system or component has flown prior to removal.

While over a long period this has a somewhat averaging out effect, it can be very misleading, particularly during the introduction or expansion of an aircraft fleet.

Newer aircraft introduced into a fleet of older aircraft of the same type usually incorporate continuous product improvements. They generally operate for longer periods without the need for special maintenance or repair activity, than their predecessors because of their improvements as well as their newness; although, they are all of the same type. This has an effect of diluting the real aircraft direct maintenance costs during the newer aircraft introductory period until these aircraft systems and components have matured. It is possible for an airline to lower the maintenance cost of a given aircraft system during a specific period just by increasing the size of its fleet with new or newer aircraft. The inverse is equally true. During a period of fleet reduction (e.g., a fleet retirement program), the remaining aircraft flying hours are usually used as the basis for measurement of the larger fleet system costs (i.e., costs incurred on the aircraft disposed during the reporting period). Similarly, management directives and special maintenance programs can influence aircraft maintenance and direct operating costs both over the short and long term.

Therefore, to assess the effects of an improvement, one must always be aware of the fleet size, age, maintenance program revisions and management philosophy during the period under review; otherwise, a false impression of either improvement or decline could be gained.

The foregoing are some of the factors that influence maintenance costs over a specific period of time and suggests caution be used when reviewing airline published or proprietary cost data; otherwise, improper conclusions could be drawn. Interpretation of the experience data used during the study program took into account all of these factors.

Maintenance Cost Element–Outside Services.–Outside services, i.e., non-airline owned offsite facilities, are used to complement and supplement the machine tools and processing facilities usually owned and operated by the airline. These outside service facilities are utilized to avoid the expensive investment in short term use equipment, such as that necessary for special or highly complex machining operations. They can be used for specialized repair or refurbishment processes; e.g., "d" (denotation) gun application of tungsten carbide; ni-gold (nickel-gold) furnace brazing, etc., of components. Outside services are also used for peak demands occasioned by campaign type modifications and repairs that have caused the in-house facilities to be load saturated.

When economics (dollar volume) justify, consideration is given to expanding the in-house capability through capital investment in additional tooling and facilities. Examples of equipment purchases to perform in-house repair of aircraft components that were previously subcontracted to outside vendors are:

1. Electron beam welding machine

2. Electrostatic discharge milling machine

3. Flame spray equipment

4. Vacuum furnaces

5. Digital controlled milling machines

On occasion, a number of aircraft components are coated with materials by a proprietary process, requiring their return to the manufacturer for refurbishment and/or repair. Again, when economics justify, licenses to perform such repair/refurbishment processes in-house are sought from the manufacturer.

Experience has shown that aircraft maintenance material costs are usually reduced by such in-house activity as the investment in material to maintain the pipeline to the vendor's facility, and the vendor's overhead charges are eliminated.

There are instances, however, where the vendor, because of volume from the total industry and his expertise in the repair/refurbishment procedure, is able to perform a service at a cost much lower than the airline would be able to perform that service in-house.

Increasing labor costs in the airline industry, coupled with a better awareness of the potential repair market of many products by more enlightened manufacturers, has resulted in increasing use of this approach. For example, it is currently more economical to send aircraft tires to specialized vendors and manufacturers for recapping than perform the work in house.

Figure 48 exhibits the outside services activity in relation to the introduction in-house of each aircraft type. The spike at the 15th year was brought about by 747 and DC-10 airframe modification programs at their respective manufacturers.

Figure 49 displays the cumulative capital investment for machine tools, special process equipment, jigs, fixtures and facility expansion, etc., to prepare for the introduction in house of additional aircraft types and the increasing need of further repair capabilities.

Material Consumption and Repair.—Material consumed during the operation, maintenance and repair of an aircraft system falls into three basic categories. These are EXPENDABLE, REPAIRABLE, and LIFE LIMITED parts. There is a fourth type of material, namely "ROTABLES," which is the term given to an aircraft system Line Replaceable Unit (LRU) or removable subcomponents of the line replaceable unit usually capable of replacement when the LRU is installed in an aircraft. Rotables, however, also consist of the three basic categories and therefore need not be treated separately.

Each of the categories are defined as follows:

1. Expendable Parts
   Items for which no authorized repair procedure exists and whose cost of repair would normally exceed that of replacement. These are further categoried into the following groupings for control purposes.

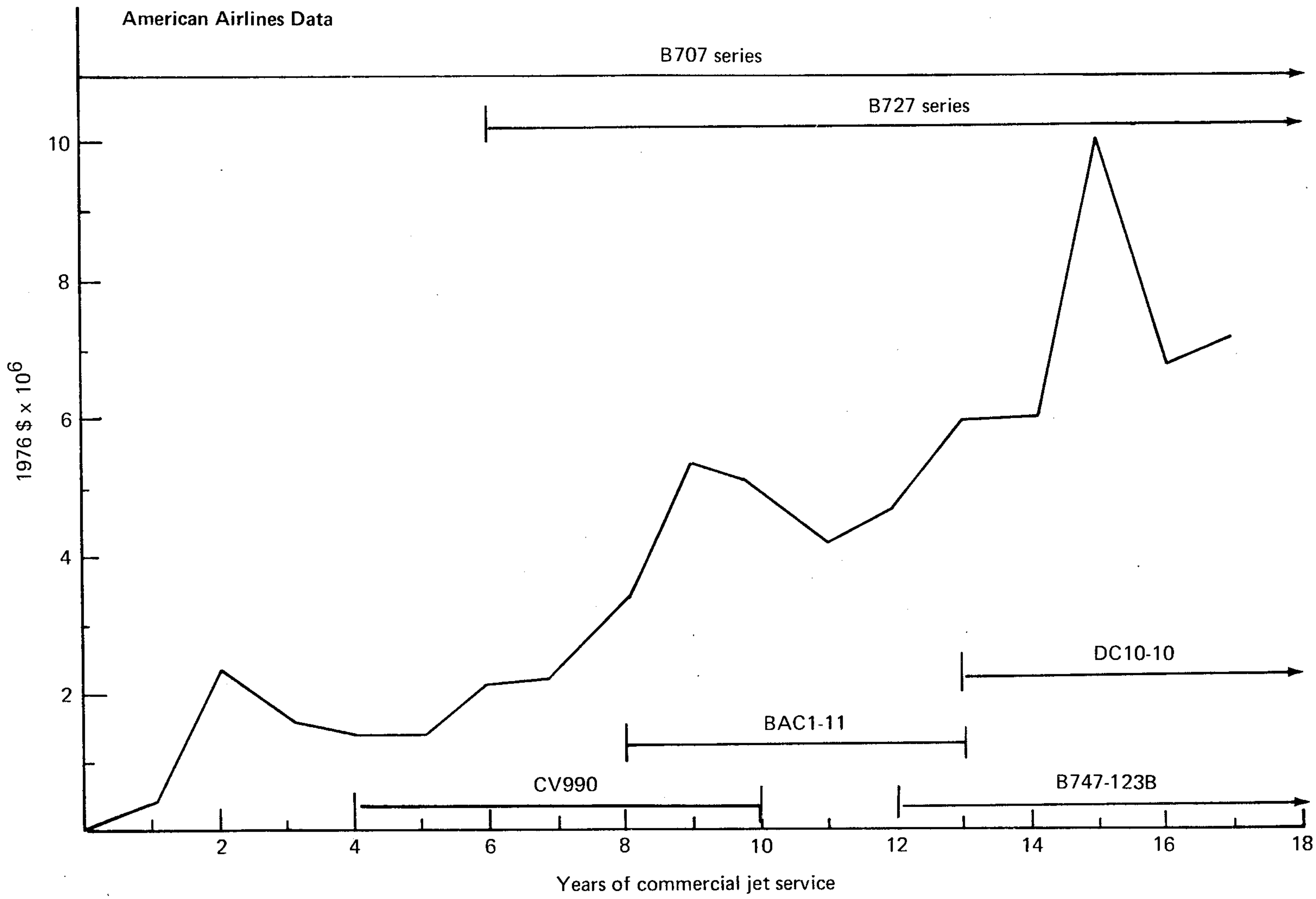

Figure 48.—Annual Outside Service Costs (1976 $)

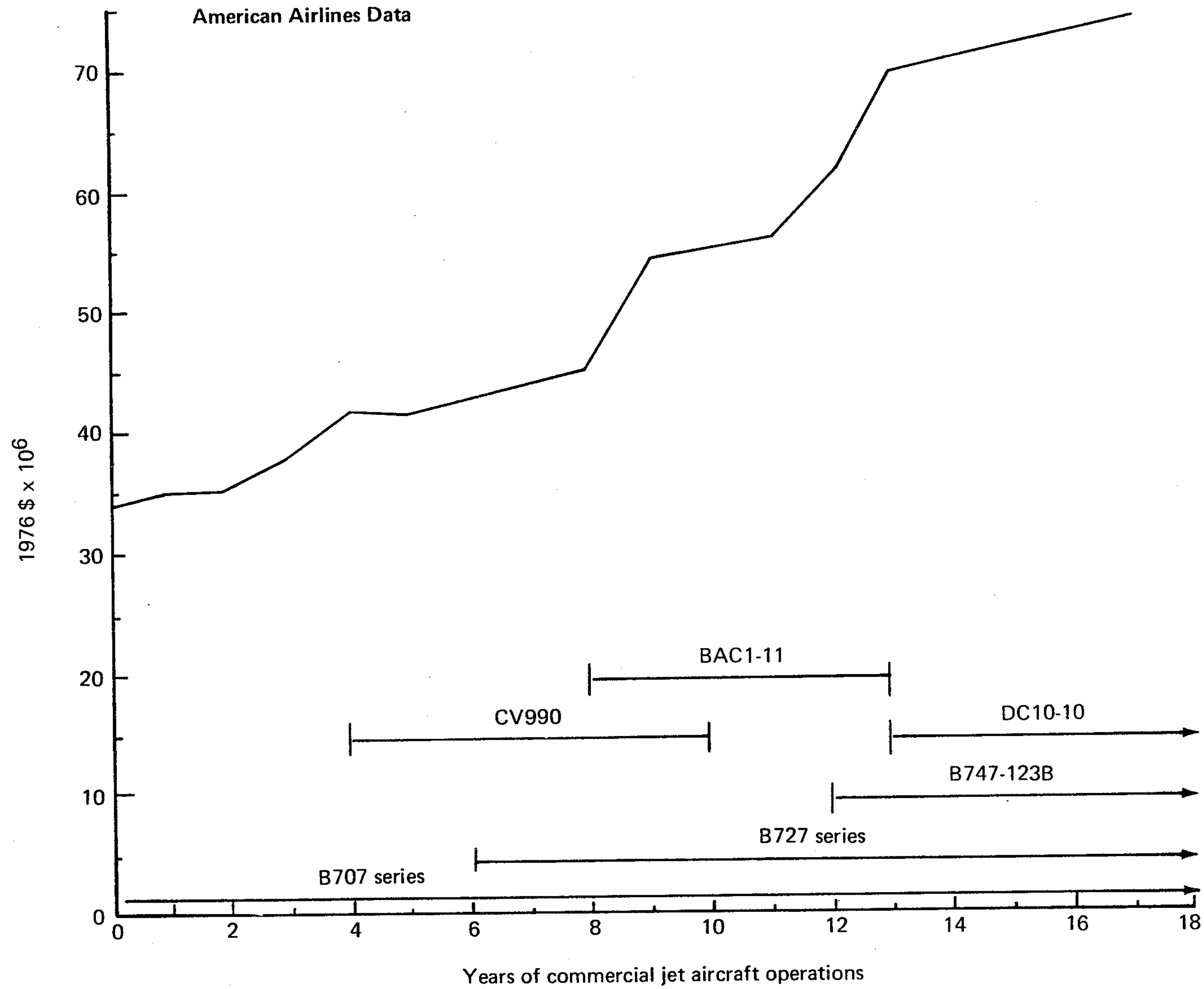

Figure 49.—Cumulative Capital Investment in Tooling and Facilities

(A) Mandatory (100%) Replacement Items
Those required to be discarded and replaced at each disassembly in keeping with overhaul specifications and/or procedures, e.g., packings, seals, gaskets, back-up rings, diaphragms, cotter pins, etc. Shop requirements are forecast using assembly production rates, quantity of article per NHA (next higher assembly) with an added allowance for loss, damage, inspection, rejection, etc.

(B) On Condition Replacement Items
Includes both integral and nonintegral piece parts of assemblies that are reused or replaced based on inspection findings. Some reclamation is possible through simple refurbishment or adjustment processes. Examples of integral items are: dowels, pins, studs, inserts, bushings, sleeves, guides, etc. Examples of nonintegral items are: bearings, races, springs, covers, orifices, housings, hoses, wire, bulbs, brackets, etc.

(C) Hardware Items
Includes bolts, nuts, washers, screws and other fastening devices removed or disturbed during assembly, overhaul or maintenance. Actual usage is a product of volume. True attrition is a function of amounts nonreclaimable through simple refurbishment processes; i.e., cleaning, sorting, identification, packaging, etc. Reclamation may be performed by the airline internally or through routing to outside agencies specializing in this function.

(D) Bulk Material
Includes materials such as liquid, paste, cloth, plastic, or comparable composition used in random quantity during overhaul or maintenance processes. Examples are: oil, chemicals, paints, cleaners, solvents, abrasives, metals, fabrics, etc.

2. Repairable Parts
These are detailed or nondetailed assemblies which, by means of an authorized repair or recovery procedure, may be continually returned to a fully serviceable condition provided economic factors justify their repair in lieu of replacement.

3. Life Limited Parts
Certain aircraft components are life limited on a flight hour or cycle basis. These are primarily structural components and consist mainly of the fuselage, wings, and landing gear assemblies. Such life limits are established and continually verified to preclude failure which could cause an unacceptable risk to the airplane occupants in addition to persons on the ground.

In the case of the fuselage and landing gear, the governing factor is usually cyclic history. This cyclic history must be kept in two forms, viz., the total number of cycles operated and the number of cycles remaining to achieve the life limits. A maximum life limit is established for certain parts regardless of condition.

Each of the following are considered as one cycle:

NOTE: Item (a) applies to all flight; Items (b) and (c) apply to pilot training flights only.

(a) A typical flight consisting of start, takeoff, climb, cruise, descent landing and shutdown.

(b) An airstart/engine shutdown and start during flight.

(c) A touch and go landing.

Where the life limiting parameter is hours, this is normally measured in flight house; i.e., the time period between wheels off during takeoff and wheels on during landing. Unit hours, therefore, become a multiple of aircraft flight hours in relation to the number of units of that particular type installed.

Again, operating history is retained in two forms, viz., total flight time accrued since new or flight time since last installed (as determined by the controlling parameter), and the number of flight hours remaining. Total flight accrued is the summation of the number of installed flight hours achieved.

4.4.6.3 Data Base

A large portion of the base data used for the airframe maintenance cost analysis was taken from American Airlines internal cost accounting system for the years 1974 and 1975. The data reporting was such that airframe and engine maintenance could be separated, even down through a maintenance level corresponding to line checks. Consequently, the data base is virtually pure airframe, with only a few miscellaneous items that had to be allocated to engine or airframe on a percentage basis. Direct labor, material, and outside services costs were separately reported for each ATA system and for each airplane type. The relative maintenance cost distribution for American Airlines is shown in figure 51. The distribution of maintenance costs by airframe ATA system is shown in figure 50 for each of the airplane types within the American Airlines' data base. About half of the maintenance expense is generated by 3 or 4 of the 26 systems.

The 1974 and 1975 data were combined and adjusted to 1976 levels, with the following economic factors being used to escalate the 1974/1975 costs to constant 1976 dollars.

	Material and outside services	Labor
1976	1.00	1.00 ($9.50/MH)
1975	1.08	1.13 ($8.39/MH)
1974	1.16	1.25 ($7.62/MH)

These data were then compared with industry source data. Suspiciously high or low points were investigated in detail, and a few discrepancies were found. For example, the 747 costs were found to be very high for some ATA systems; investigation showed that some costs of converting 747 passenger airplanes to freighter configuration were improperly charged to the 747 passenger airplane rather than the freighter. In addition, the extremely low utilization rate of these 747s contributed to very high routine costs per hour. One specific item of note was the discovery of a computer programming error which caused work on components from all airplane types at one repair station to be charged to the 747 avionics system during the data base period. This included work done by American Airlines for

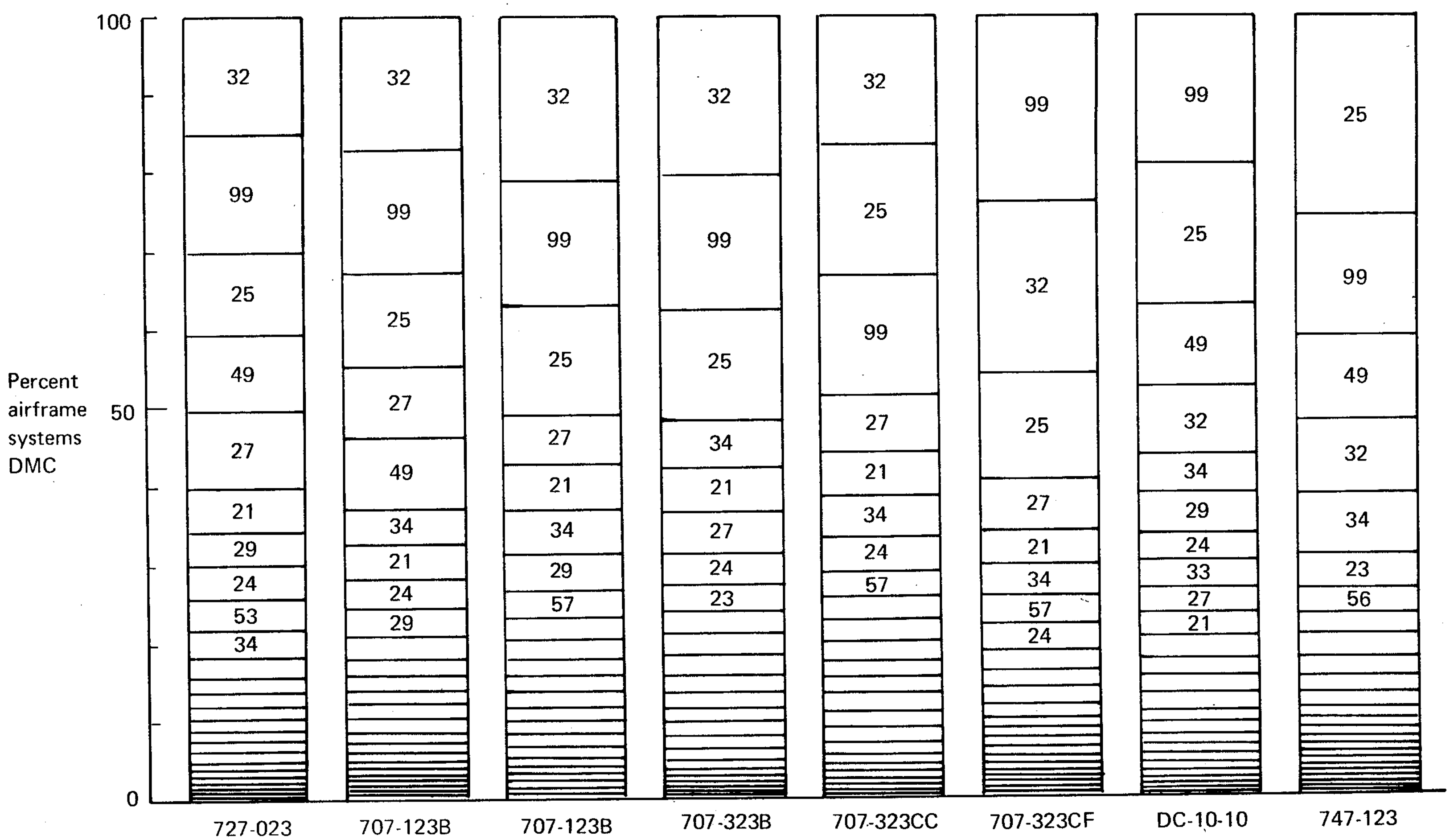

Figure 50.—Airframe Systems Maintenance Cost Distributions—American Airlines

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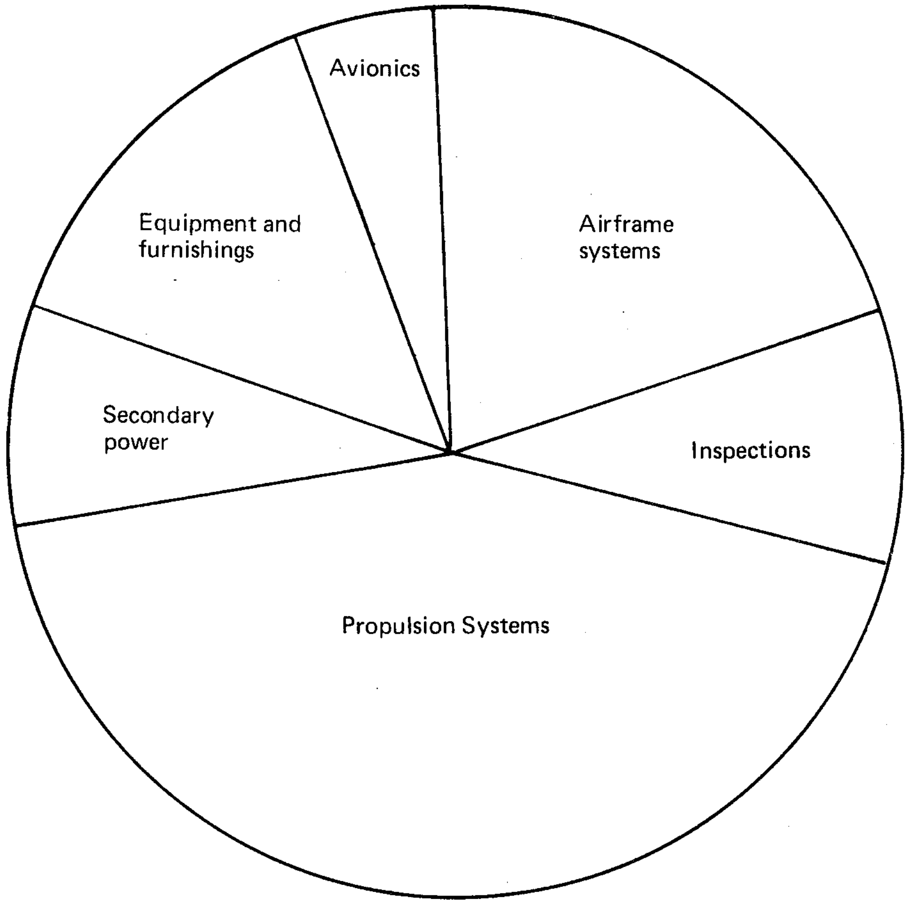

Figure 51.—Relative Maintenance Cost Distribution for American Airlines

other airlines. In such instances as these, the erroneous points were deleted from the system analysis charts, being supplemented in many cases with industry source data.

The industry source data is a compilation of detail inputs from many customer airlines. Since few airlines report data on an ATA system basis, the maintenance data were examined by part number and maintenance card item and allocated to the correct system.

This provides reliable shop and line data for the top 500-800 cost items with the maintenance task card examination furnishing the additional system cost data. It also must be noted that American Airlines data itself is part of the industry source data that is included in the average values shown for industry source data. Boeing data for the 737 were added in addition to the data for airplanes being operated by American Airlines to provide an expanded data base.

Source data	737	727	707	DC-10	747
American Airlines	—	P	P	P	P
Boeing	P	S	S	—	S

P = Prime
S = Secondary

4.4.6.4 Effects of Design Maturity and Fleet Dilution

Maintenance costs vary with time in airline service and design maturity at the time an airplane enters service. Learning on the part of a manufacturer as service experience is gained, learning on the part of an airline after the introduction of a new model, the effect of wear increasing with age, and other factors all interrelate to affect maintenance costs. In addition, the dilution of a fleet with new airplanes will change the maintenance cost of the fleet.

CAB form 41 data was the only data readily available from which to illustrate the effects of design maturity and time in service on maintenance costs. Suitable long term historical summaries of line station maintenance expense were not available, and the summaries of shop and outside service maintenance costs that were available did not show the same patterns as the CAB 41 data indicating that they alone would not be meaningful. The data from the CAB form 41 reports shown in this section were normalized by design seat capacity since the detailed maintenance cost studies which follow show this to be a major expense scaling factor.

The seventeen (17) year airframe maintenance expense history of the 707-123 airplane type, illustrated in figure 52, is the product of a number of factors, such as design improvements, labor learning, maintenance practices evolution, design-for-maintenance, and state-of-the-art evolution. The most significant element, in addition to the early learning curve, was the fact that the 707 represented a substantially newer technology than that already in operation. This resulted in mandatory major maintenance intervals required by the FAA that were far lower than those required for new airplane types entering service today (i.e., major airframe structural inspections and maintenance at 3500-4000 flight hours versus 9000-12 000 hours). This trend may be applicable to an entirely new/advanced technology airplane with radical changes to existing experience. It is believed that most of the debugging and labor learning takes place within the first four or so years as is indicated by the historical trends of mechanically caused delays shown in section 4.5, and as was found with respect to the engine removal rate reported in reference 1. It was therefore inferred that the trend line based on data starting with the sixth year reflected the general evolution of design state-of-the-art and airline maintenance practices and would generally represent all aircraft designs of a common basic technology. This appears to be confirmed by the historical data of the other Model 707 aircraft types shown in figure 52. Other American Airlines' models are shown in figure 53 and their trends compared to those of the 707-123. Differences from the 707-123 state-of-the-art trend line can be generally accounted for by varying flight length effects and dilution rates.

The derivative aircraft models generally all show a significantly lower maintenance cost for the first three to four years of operations. This is due to warranty guarantees, newness effects, and because a derivative airplane benefits from product improvements, and can exploit the benefits of mature maintenance programs. The introductory maintenance costs for newly developed aircraft appear to be partly compensated by warranty provisions and maintenance expense lag (newness effects). Without warranty protection, introductory maintenance costs for new aircraft would be higher than experienced. The effects of derivative aircraft on maintenance costs is clearly illustrated when considering the 707 family of airplanes (fig. 52).

This same effect of low maintenance for the first few years of operation as indicated by the derivative 707 airplanes (320B and 320C) would apply to new airplanes being added to a fleet of the same type of airplanes. For instance, 22 of the DC-10-10's in the American Airlines' fleet were delivered through 1972 and would still be causing lower than expected fleet maintenance through the 1974, 1975 data period.

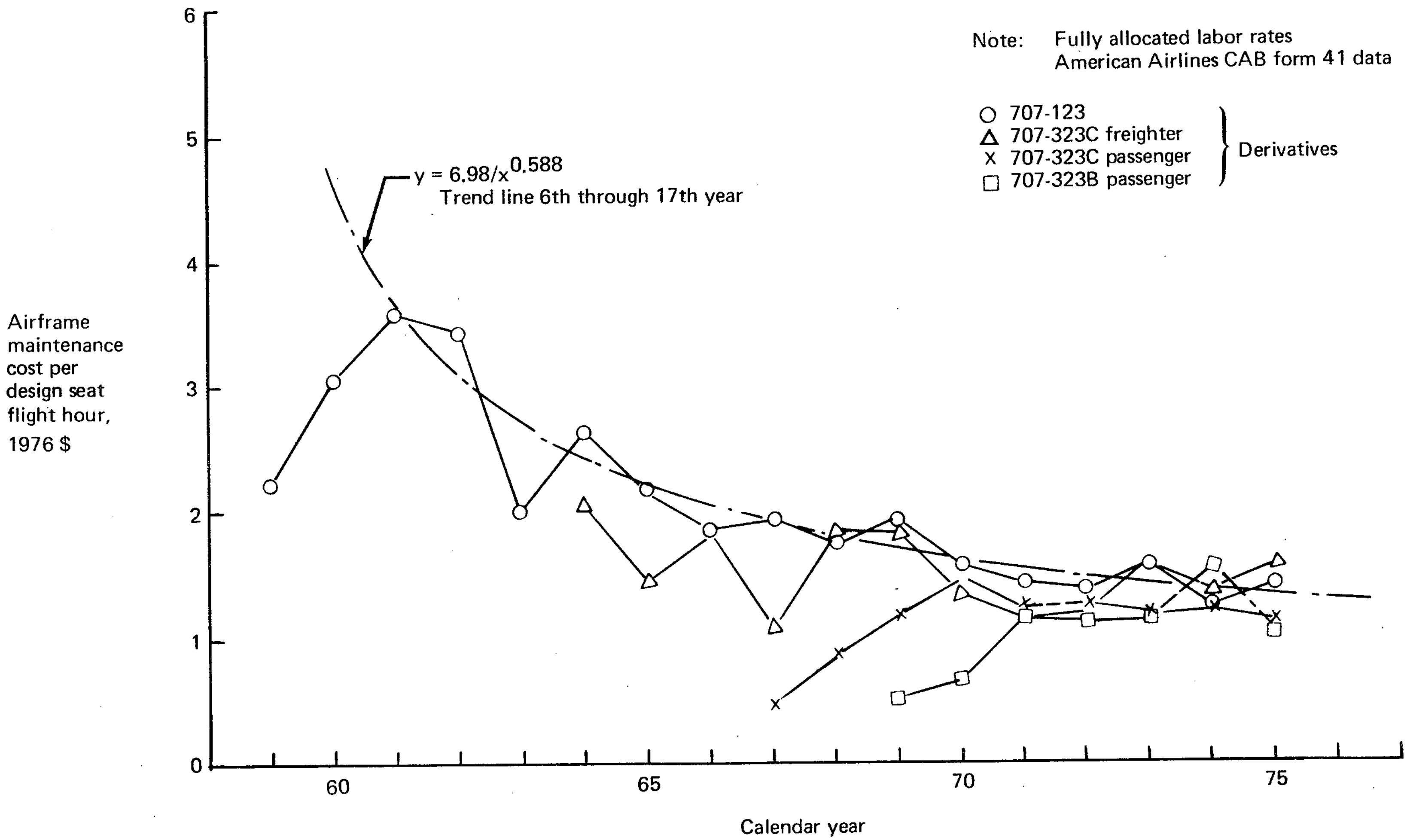

Figure 52.—Airframe Maintenance Cost Historical Trends—Model 707 Aircraft

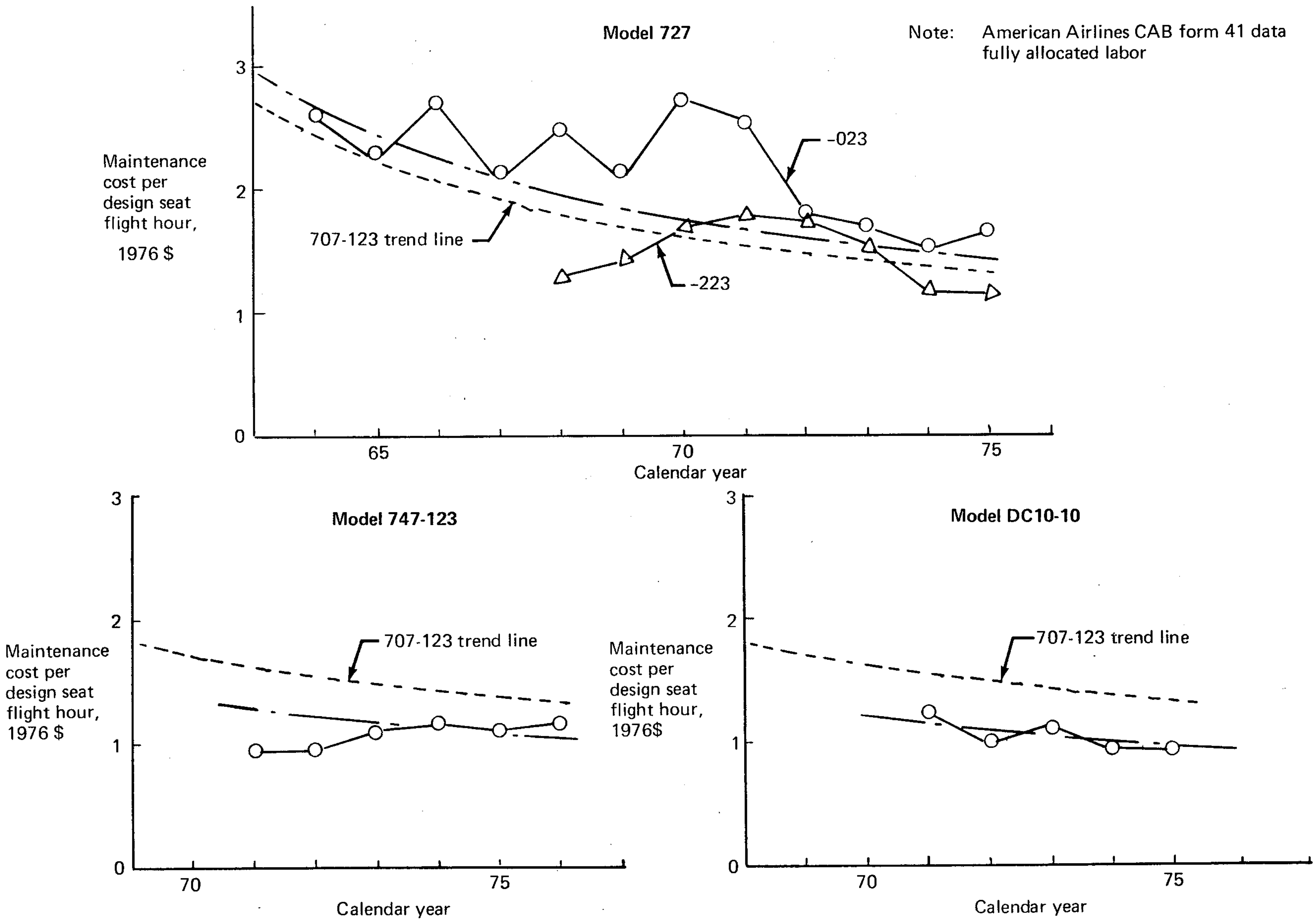

Figure 53.—Airframe Maintenance Cost Historical Trends—Models 727, 747, and DC-10

There were also four 727-200's added to the fleet during the last three quarters of 1975 which would cause some dilution of the 727-200 fleet, although the fleet would be small since the 727-200 fleet had 46 total airplanes. Since the effect of new airplane dilution was expected to be less than 5% of the total costs it was neglected in this study due to the inability to exactly define the results.

The newer aircraft designs (727, 747, DC-10) shown in figure 53 appear to have initial values which are close to the overall trend line and/or the mature values for the 707 models. From this it is tentatively concluded that the expense of debugging and learning, are approximately compensated for by the warranty provisions and the significant maintenance expense time lag since the new airplanes involved are not radical departures from current technology.

4.4.6.5 Adjustment For Outside Services

The method developed herein is intended to represent airframe maintenance costs for an airline doing all maintenance in-house. In reality, virtually every airline has some repair accomplished by outside vendors and specialized shops. During the data base years, American spent approximately 12% of total maintenance dollars on outside services, with approximately 6% of narrow body airplane costs being outside expenses and nearly 30% of the wide body costs being outside. To arrive at an equivalent in-house total for direct maintenance costs, certain assumptions were made and the data adjusted accordingly.

It was assumed that outside services costs include a 10% profit margin over and above direct labor, material, and burden costs. The burden was assumed to be 200% of direct labor, which is representative of industry reported data. For each ATA system, the direct labor and material costs for the outside services were assumed to be in the same proportion as the in-house data for the narrow body airplanes since they had little outside service expenses. The following method was used for each ATA system:

L = direct labor cost
M = direct material cost
Burden = 200% direct labor cost
Profit = .1 (L + M + Burden)
Outside service cost = profit + M + L + burden
= 1.1(M + 3L)

For each ATA system a relationship between material and labor can be defined:

$$L = KM$$

To obtain the equivalent in-house costs for an outside service charge

$$L = \frac{\text{Outside service cost}}{1.1\ 3 + \frac{1}{K}}$$

$$M = \frac{\text{Outside service cost}}{1.1(1 + 3K)}$$

The resulting equivalent in-house labor and material costs were then added to the in-house labor and material to arrive at a total cost representative of all maintenance being accomplished in-house.

4.4.6.6 Flight Hour/Flight Cycle Adjustment

An airline with a mixed fleet of airplanes will generally have a different average flight length for each airplane type according to the route system on which they are flown. For American Airlines, the average flight length varies from 1.33 hours for the 727-100 to 3.33 hours for the 747. To provide a consistent point of comparison for the entire fleet, the maintenance cost data was adjusted to a flight length of 2.5 hours, similar to the stage lengths of the 707, DC-10-10 fleets. This was done by using the flight cycle/flight hour relationships from reference 13 ("Distribution of Maintenance Costs Per Cycle & Per Operating Hour", BCAC Operational Economics Unit, A849R2, September 1977).

As explained in reference 13, airplane maintenance costs tend to be dependent on the number of hours flown, and also dependent on the number of flights (or cycles). The reference 13 study was based on actual maintenance costs, reported by ATA system, for 727-200 airplanes operated by the same airline over two distinct route systems of different average flight lengths. From these studies a cycle/flight hour ratio was calculated for each ATA system as provided on table 10. Further analysis of airframe maintenance data for other airplane types indicated a close relationship to the cycle/flight hour ratios of the 727-200 airplane study. Because of this relationship it is possible to extrapolate from the 727-200 ATA systems baseline to project systems costs for other airplane types. The relationships are defined as follows for a flight length of one hour:

$$\text{Flight hour dependence} = FH = \frac{\text{Flight hour related cost}}{\text{Total direct maintenance cost}}$$

$$\text{Flight cycle dependence} = FC = \frac{\text{Flight cycle related cost}}{\text{Total direct maintenance cost}}$$

(Note that $FH + FC = 1.0$)

Given the cost at one hour, the cost can then be calculated for any flight length, where:

FL = flight length, hours

$$[\text{Cost}]_{@\,FL} = [\text{Cost}]_{@\,1.0\text{ hr}} \times [FL \times FH + FC]$$

This method was applied to the data for each airplane type, where:

FL_{avg} = Fleet average FL for a given airplane type
Lab \$ = Direct labor per trip @ FL_{avg}
Mat \$ = Direct material per trip @ FL_{avg}

$$\text{Labor/trip @ 2.5 hrs} = \text{lab \$} \times \left[\frac{2.5\,FH + FC}{FL_{avg} \times FH + FC}\right]$$

$$\text{Material/trip @ 2.5 hrs} = \text{mat \$} \times \left[\frac{2.5\,FH + FC}{FL_{avg} \times FH + FC}\right]$$

This calculation was done for every ATA system for each airplane type, thus giving a consistent set of labor and material costs with flight length effectively removed as a variable. For an example of this calculation, see paragraph 4.4.6.8.

4.4.6.7 Parametric Analysis

After the necessary adjustments were made to the data base, the data for each ATA system was examined to determine the most appropriate parameter or parameters to represent maintenance costs. In some cases the choice of parameters was obvious, while in other cases the regression analysis was tried with several different parameters to find the parameter giving the best correlation. In a few cases, the data did not seem to correlate with any logical parameter. For details on the individual systems, refer to the notes accompanying the individual system charts in section 4.4.6.9.

The following example calculations illustrate the steps involved in adjusting the data base and deriving the parametric equations.

4.4.6.8 Example Calculations

System 25 contains those removable items and furnishings contained in the flight, passenger, cargo, and accessory compartments. These items include flight crew seats and accessories, passenger seats, storage areas, floor coverings, galleys and equipment, lavatories (except that covered in System 38), passenger entertainment system (except MUX contained in System 23), cargo compartment and cargo handling equipment, and emergency equipment.

ATA System 25 costs for the 727-200 are used here as an example to illustrate the adjustments made to the data base and the derivation of the maintenance cost equations. From the American Airlines data base, the 1974 and 1975 costs were escalated to 1976 dollars. An average, weighted by the number of 727-200 flights per year, was then calculated:

ATA 25 maintenance costs for 727-200
1974-75 weighted average, 1976 dollars

In-house labor/trip = \$6.659
In-house materials/trip = 2.588
Outside services/trip = .096

The ratio of labor cost to material cost for ATA 25 was calculated on the basis of all narrow body airplanes in the data base:

$$\frac{\text{Labor}}{\text{Material}} = K = 2.236$$

Using the equations of paragraph 4.4.5.6, the direct labor and material portions of outside services were calculated:

$$L = \frac{\text{Outside services cost}}{1.1\ 3 + \frac{1}{K}} = \frac{.096}{1.1\left(3 + \frac{1}{2.236}\right)} = .0253 \text{ \$/trip}$$

$$M = \frac{\text{Outside services cost}}{1.1(1 + 3K)} = \frac{.096}{1.1[1 + 3(2.236)]} = .0113 \text{ \$/trip}$$

These outside services costs were then added to in-house labor and material costs to get total direct maintenance costs (if all work were done in-house:

$$\text{Lab \$} = \frac{\text{Direct labor}}{\text{Trip}} = \$6.659 + 0.0253 = \$6.684$$

$$\text{Mat \$} = \frac{\text{Materials}}{\text{Trip}} = \$2.588 + 0.0113 = \$2.599$$

These values for 727-200, ATA System 25, were then adjusted to a 2.5 hour flight length. For American Airlines' 727-200 fleet, the average flight length was

$$FL_{avg} = 1.385 \text{ hours}$$

From table 10 the flight hour and flight cycle dependence for ATA 25 are

$$FH = .38 \qquad FC = .62$$

Using the equations of paragraph 4.4.5.7:

$$[\text{Labor/trip}]_{2.5 \text{ hrs}} = \text{Lab \$} \left[\frac{2.5 \times FH + FC}{FL_{avg} \times FH + FC}\right]$$

$$= 6.684 \left[\frac{2.5(.38) + .62}{1.385(.38) + .62}\right] = \$9.155$$

$$[\text{Material/trip}]_{2.5 \text{ hrs}} = \text{Mat \$} \left[\frac{2.5(.38) + .62}{1.385(.38) + .62}\right] = \$3.560$$

Figure 54 illustrates the rationale for adjusting all data points to a constant 2.5 hour flight length before making a regression to establish the best correlation of the data. Each solid line represents the effect of flight length on trip costs for each of the specific interiors (System 25) of the airplanes represented as a data point. It would be expected that the ATA System 25 costs for a short range, lower comfort level, minimal galley size design airplane would be lower than the costs for an airplane designed with more passenger comfort and increased galley capability at the same stage length as is shown. However, a simple approach would have been to make a regression through the data points using flight length as the variable. As indicated this would match the data points fairly well at each of the specific flight lengths but would introduce errors at other flight lengths.

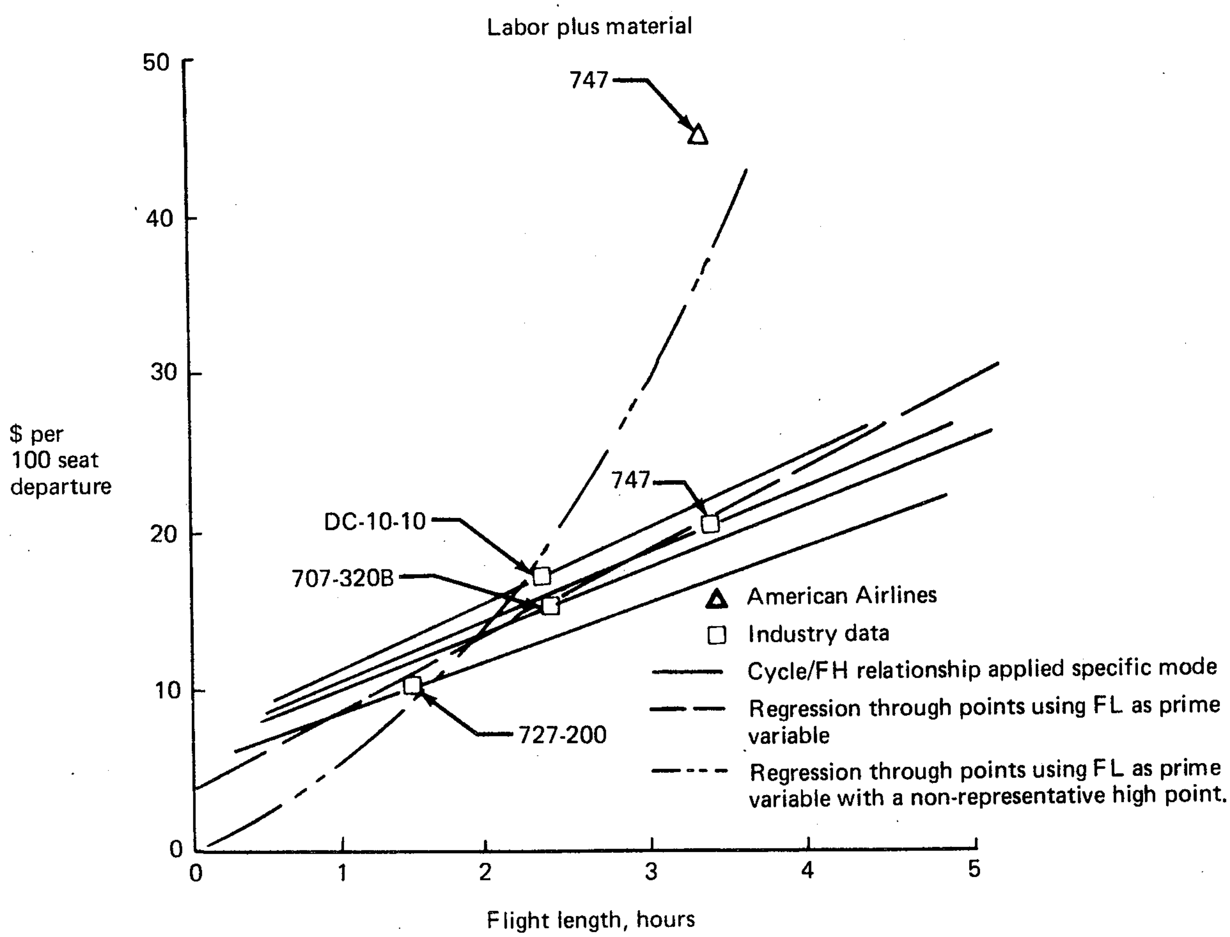

Figure 54.—ATA System 25 Equipment/Furnishings

Also, by eliminating flight length as a possible variable, it is much easier to identify points that are unusually high or low and omitting them from the data correlation. If the triangular point were substituted at 3.3 hours it would not be readily apparent that it should not be used as a valid point in the data regression using flight length as a variable. This would result in an expression with flight length to a power which would result in very dramatic errors at other flight lengths. By referring to the parametric charts for System 25, it was readily apparent that the point was unusual and was deleted from the analysis.

Design Complexity Factor.—It will be noted that there are four systems (ATA Systems 25, 33, 34, 38) where range or seats would seem to be the logical correlating parameter, but where a factor times the number of seats actually provided better data regression for all four systems. This is particularly significant since all four systems use this same factor. This factor, designated as complexity factor, infers that the system is much more complex when in fact it generally means that increased capability was provided.

ATA Systems 25, 33, and 38 (Equipment and Furnishings, Lighting, and Water/Waste respectively) are all associated with the passengers and passenger comfort. The factor that had the best overall regression was 0.6 for short range operation, 1.0 for medium range operation, and 1.6 for longer range operation. The factor assigned however, is not totally range dependent or it would have been used as a correlating parameter. It is based on the design objectives for the airplane and its expected operation i.e., one meal or cold snack galley sizing for the shorter range operation (737, DC-9, etc.), and 3-3.5 hot meals per trip capability on the longer range aircraft (DC-10, L1011, 747), passenger entertainment earphones versus movies, single aisle space versus more roomy double aisle comfort, etc. ATA System 34 navigation indicates a difference which is again design sensitive with standard short range navigation on all airplane models with the additional provisions for long range requirements for systems like INS on the long range aircraft. The 707 was designed for long range operation with a navigator station and long range navigation capability. It has since been operated on shorter average stage lengths where the long range capability is not required.

The complexity factors as identified previously were selected to provide a size-range-comfort level scalar relationship between short, medium and long range airplanes. Although every effort was made to establish a sound rationale in selecting the complexity factors, their selection is subjective to the author's reasoning. With this in mind, the user may choose to modify the complexity factors with respect to specific airplane types, configurations and flight length.

4.4.6.9 Parametric Equations—Summary and System Charts

The parametric equations for labor and material costs are summarized in table 12 for each ATA system. These equations are derived for a 2.5 hour flight length. To calculate costs for any other flight length, FL, using the values of FH and FC from table 10.

To simplify airframe maintenance cost calculations, many terms of the parametric equations can be combined to give the short form equations listed in table 14, page, 166. For engine maintenance cost comparisons, the short form equation of reference 1 are listed in table 17, page 170.

The individual Labor and Material charts on the following pages illustrate the data used for regression analysis in deriving the parametric equations. Accompanying notes indicate the points deleted for various reasons, and the various parameters examined in each case. The individual data points shown as solid symbols, (●, ▲) on the charts were used for the regression; the open symbols (○, △) show data points not used in the regression.

Table 9.—ATA Specification 100 Codes

Code	Description	Code	Description
99	Airframe-Inspection & Miscellaneous	49	Airborne Auxiliary Power
21	Air Conditioning	50	Structures—General
22	Autopilot	52	Doors
23	Communications	53	Fuselage
24	Electrical Power	54	Nacelles/Pylons
25	Equipment & Furnishings	55	Stabilizers
26	Fire Protection	56	Windows
27	Flight Controls	57	Wings
28	Fuel	71	Powerplants—General Including Cowling
29	Hydraulic Power	72	Engine
30	Ice & Rain Protection	73	Engine Fuel & Control
31	Instruments	74	Ignition
32	Landing Gear	75	Engine Air
33	Lighting	76	Engine Controls
34	Navigation	77	Engine Indicating
35	Oxygen	78	Exhaust
36	Pneumatics	79	Oil
38	Water/Waste	80	Starting

Table 10.—Flight Hour/Flight Cycle Ratios

ATA System	FH	FC
99	1.00	0
21	.58	.42
22	.59	.41
23	.66	.34
24	.74	.26
25	.38	.62
26	.25	.75
27	.70	.30
28	.94	.06
29	.70	.30
30	.50	.50
31	.65	.35
32	.18	.82
33	.78	.22
34	.67	.33
35	.55	.45
36	.26	.74
38	.33	.67
49	*	*
50	1.00	0
52	.51	.49
53	.50	.50
54	.80	.20
55	.49	.51
56	.80	.20
57	.49	.51

*Refer to detail discussion of system 49 on page 135.

Table 11.—List of Abbreviations

AFW	Airframe Weight—kgs		
AC kg/min	Air conditioning total pack air flow in kilograms per minute		
CHANN	Channels		
MUX	Multiplex unit		
(N)	Number of		
GEN	Electrical generators	Short Range Operations	.6
CF	Defined complexity factor =	Medium Range	1.0
ENG	Engines	Long Range	1.6
HYD LPM	Liters per minute flow of hydraulic pumps		
INS	Inertial navigation system		
OXY GEN	Oxygen generator		
SHP	Shaft horsepower—watts		
NAC	Nacelle		
FDET	Fire detection, type engine sensors		
KE	Kinetic Energy		

Table 12.—(Long Form) Parametric Equations—2.5 Flight Hours

ATA System	Labor	Material
99	$7.66 + .377 \times AFW/10^3$	$1.21 + .062 \times AFW/10^3$
21	2.0386 + .01532 x AC kg/min	2.32 + .011 x AC kg/min
22	2.238 x (N) CHANN	.631 + .398 x (N) CHANN
23	.01772 x seats (W/O MUX) .0276 x seats (W MUX)	.00693 x seats (W/O MUX) .0118 x seats (W MUX)
24	1.336 + .00396 x (N) GEN x kVA	1.42 + .00577 x (N) GEN x kVA
25	9.11 + .0531 x seats x CF	2.38 + .0361 x seats x CF
26	.0726 x [(N)ENG + (N) APU] (single circuit) .213 + .359 x [(N)ENG + (N)APU] (dual circuit)	.082 + .0552 x [(N)] ENG + (N) APU] (single circuit) .365 x [(N)ENG + (N)APU] (dual circuit)
27	$6.84 + .0035 \times MGW/10^3$	$3.876 + .00655 \times MGW/10^3$
28	$1.114 + .0262 \times \text{kg FUEL}/10^3$	$.595 + .0123 \times \text{kg FUEL}/10^3$
29	2.31 + .0034 x HYD LPM	1.55 + .0080 x HYD LPM
30	$.5089 + .0013 \times MGW/10^3$	$.0847 + .0037 \times MGW/10^3$
31	$.509 + .009 \times AFW/10^3$	$.235 + .0031 \times AFW/10^3$
32	$4.58 + .0710 \times MGW/10^3$, or, (5.324 + 0.9453 KE) $+ (-.5361 + .0478\ MGW/10^3)$	$4.961 + .1810 \times MGW/10^3$, or, (7.6931 + .2926 KE) $+ (-3.324 + .1177\ MGW/10^3)$
33	1.51 + .0072 x seats x CF	.047 + .0087 x seats x CF
34	2.94 + 2.1 x (N)INS + 3.58 x CF	.086 + 1.2 x (N)INS + 3.675 x CF

Table 12.—(Long Form) Parametric Equations—2.5 Flight Hours (Concluded)

ATA System	Labor	Material
35	.515 + .00265 x seats	.00458 x seats (conventional) .00752 x seats (OXY GEN)
36	.181 + .0003 x AC kg/min x thrust/10^4	.0019 x AC kg/min x thrust/10^4
38	.339 + .0023 x seats x CF	.00485 x seats x CF
49*	.7185 + .0003 x [APU SHP x APU kg/min]^{½} (x 1.8 for double spool, variable vanes)	1.466 + .0007 x [APU SHP x APU kg/min]^{½} * Labor and Mat'l costs per APU operating hour
50	3 + .0099 x AFW/10^3	
52	1.147 + .006 x seats	.387 + .00785 x seats
53	1.5 + .046 x AFW/10^3	.5833
54	.3366 x Pod Nac	.1391 x Pod Nac
55	.834	.3737
56	.763 + .00043 x seats	.0284 x seats (flat windshield) .0362 x seats (curve windshield)
57	2.9475	.126 + .00506 x wing area

Routine maintenance labor is that associated with the A, B, C, and D checks. These checks and inspections are normally performed at specific hourly intervals, thus the flight hourly/cyclic breakout of these costs are assumed to be 100% hourly related. Industry source data are not shown on this chart since these data are normally pre-allocated into the various ATA systems. Because of this the ATA system charts, which show both industry source data and the American Airline data, will generally show the industry source data higher.

The American Airlines 747 point was not used in the regression since this point was unusually high possibly as a result of error in the data reporting or low utilization of the airplane by American Airlines.

Another parameter tried was spec seats which is also an indication of airplane size. Airframe weight was considered to be a better general size indicator in this instance and was used in place of spec seats.

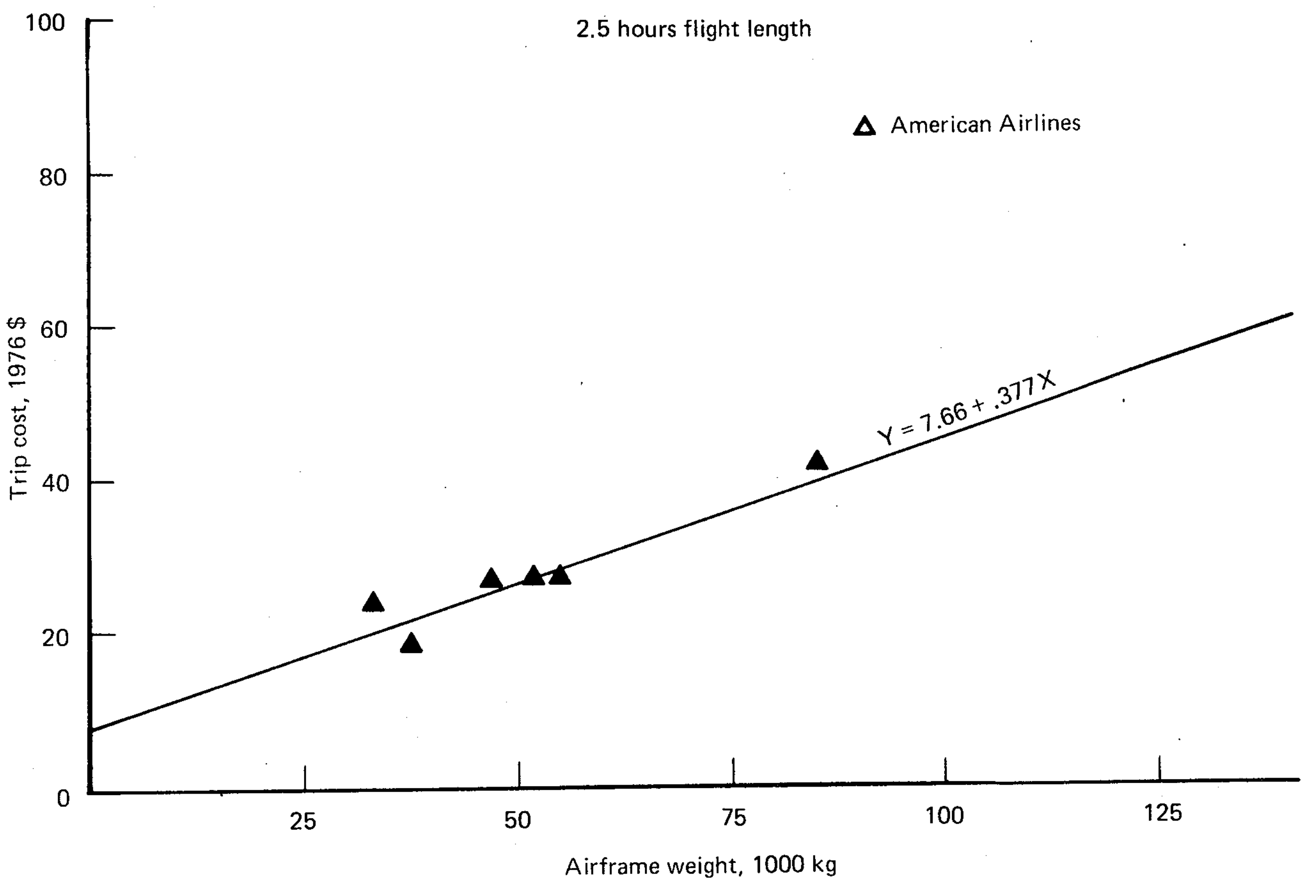

Figure 55.—ATA System 99—Routine Maintenance—Labor

This chart reflects miscellaneous material such as rivets, general hardware, etc., that did not fit into any specific ATA system category during the preparation of the AAL data. Similar to the previous chart, comparable industry source data was not available.

The DC-10 point was unusually high and was not used to regress the equation.

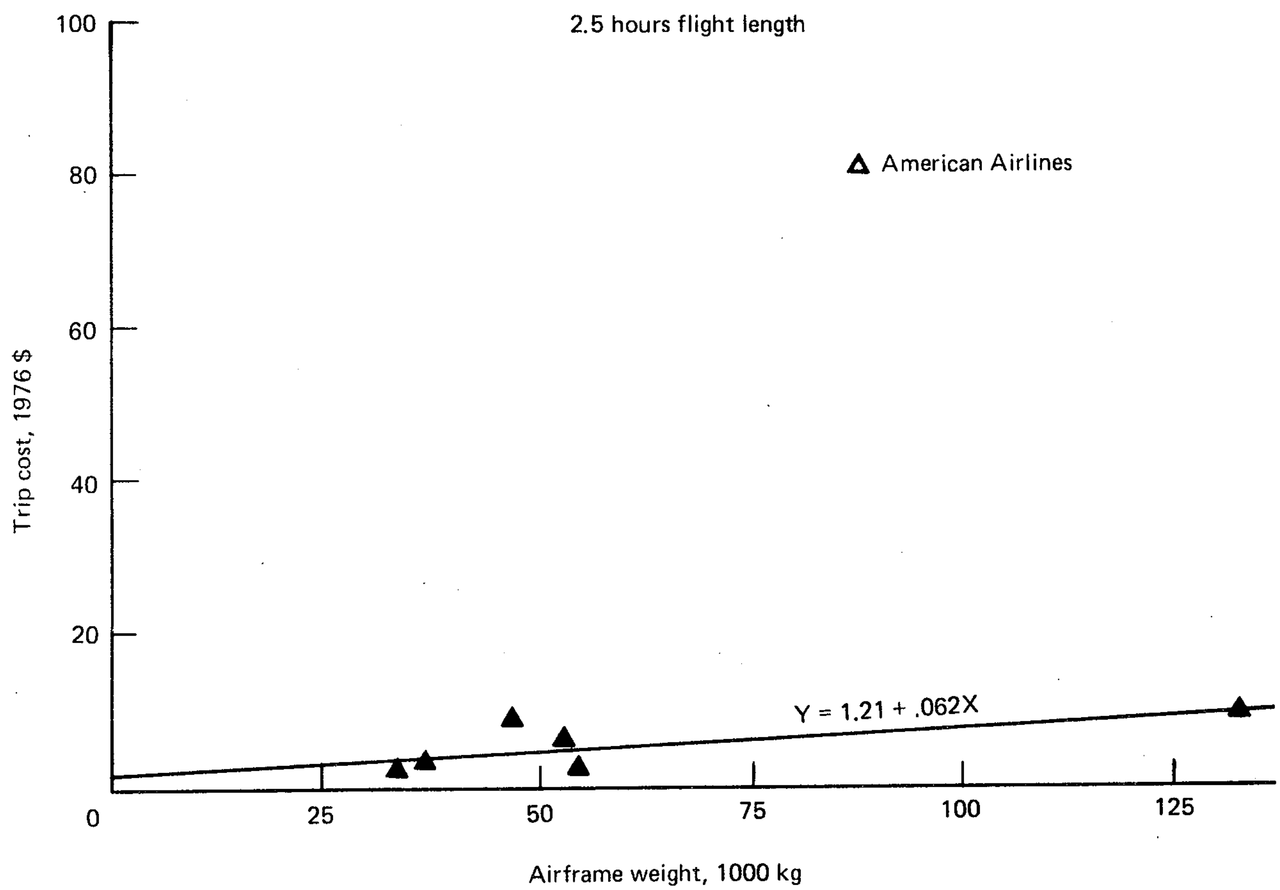

Figure 56.—ATA System 99—Routine Maintenance—Material

Industry source data was higher than AAL data due to inclusion of 99 System costs and was not used in this chart. The 707 points, shown but not used in the regression, have high labor costs which is probably a reflection of the older freon type system which was more difficult to troubleshoot.

Other parameters tried were spec seats, number of packs, and combinations of pack numbers and capacity.

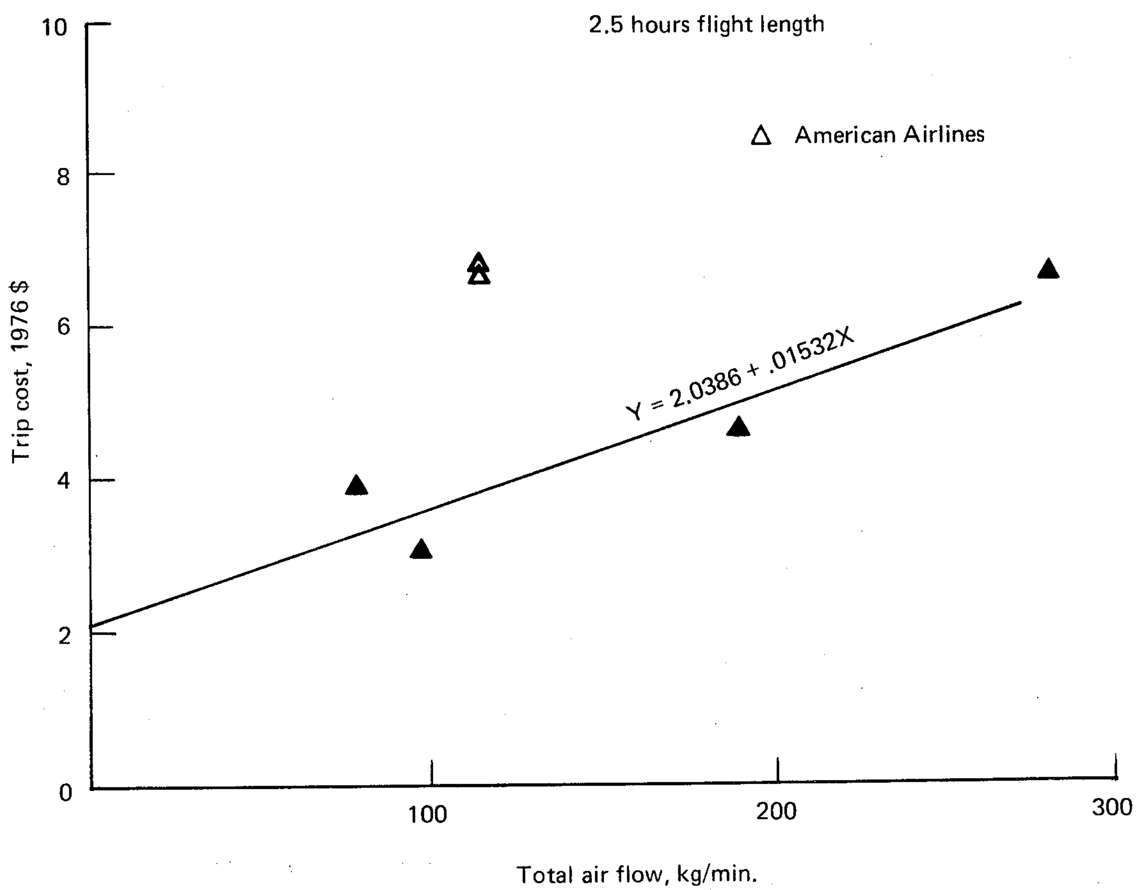

Figure 57.—ATA System 21—Air Conditioning—Labor

Industry source data for the material was less affected by inclusion of 99 System costs and are used to enrich the AAL data. The AAL 747 point was unusually high and was not used to regress the equation.

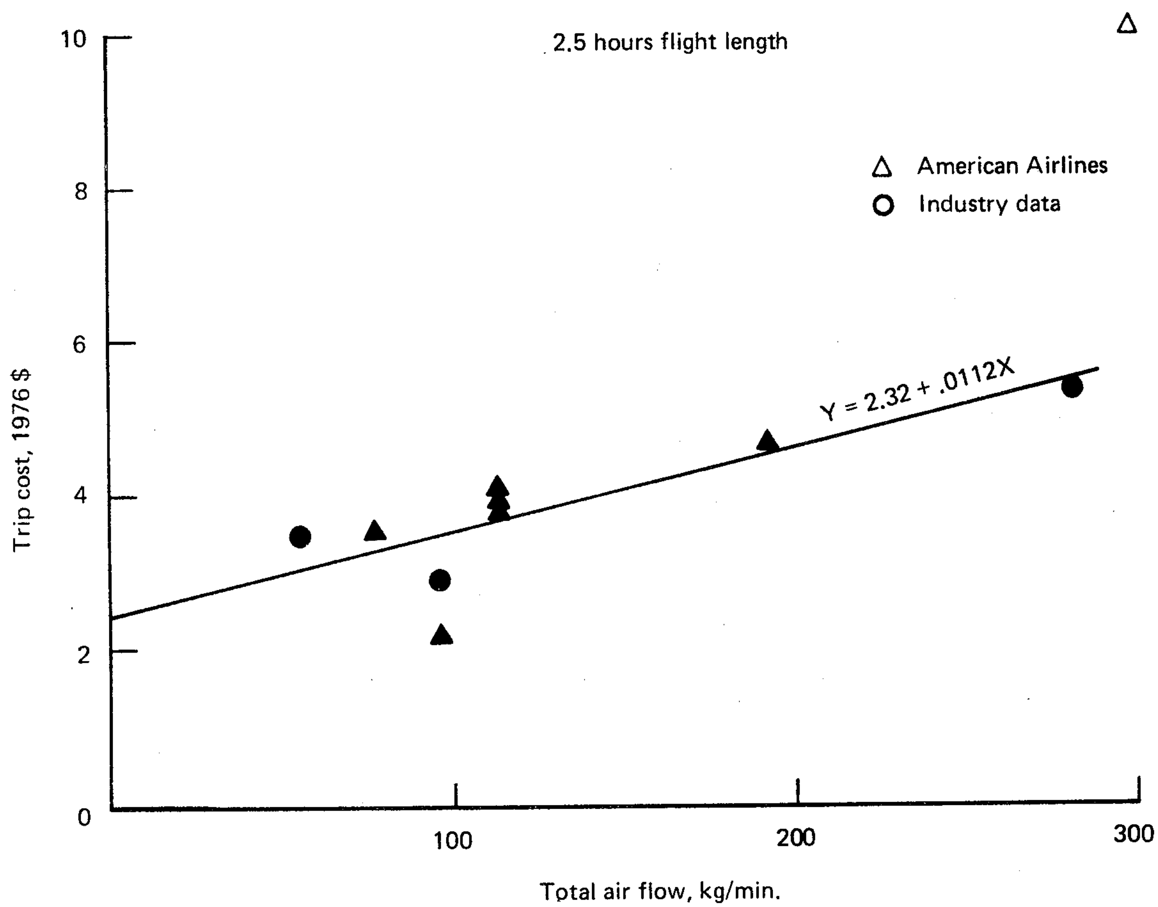

Figure 58.—ATA System 21—Air Conditioning—Material

All American Airlines and industry source data points were used in the above regression.

In an attempt to represent complexity, another parameter tried was the number of LRUs in the system. However, with the fast changing electronic technology and packaging techniques, it was felt that a count of total autopilot systems (operating channels) irrespective of the number of LRUs would be a better (and simpler) measure of current and near future autopilot system complexity.

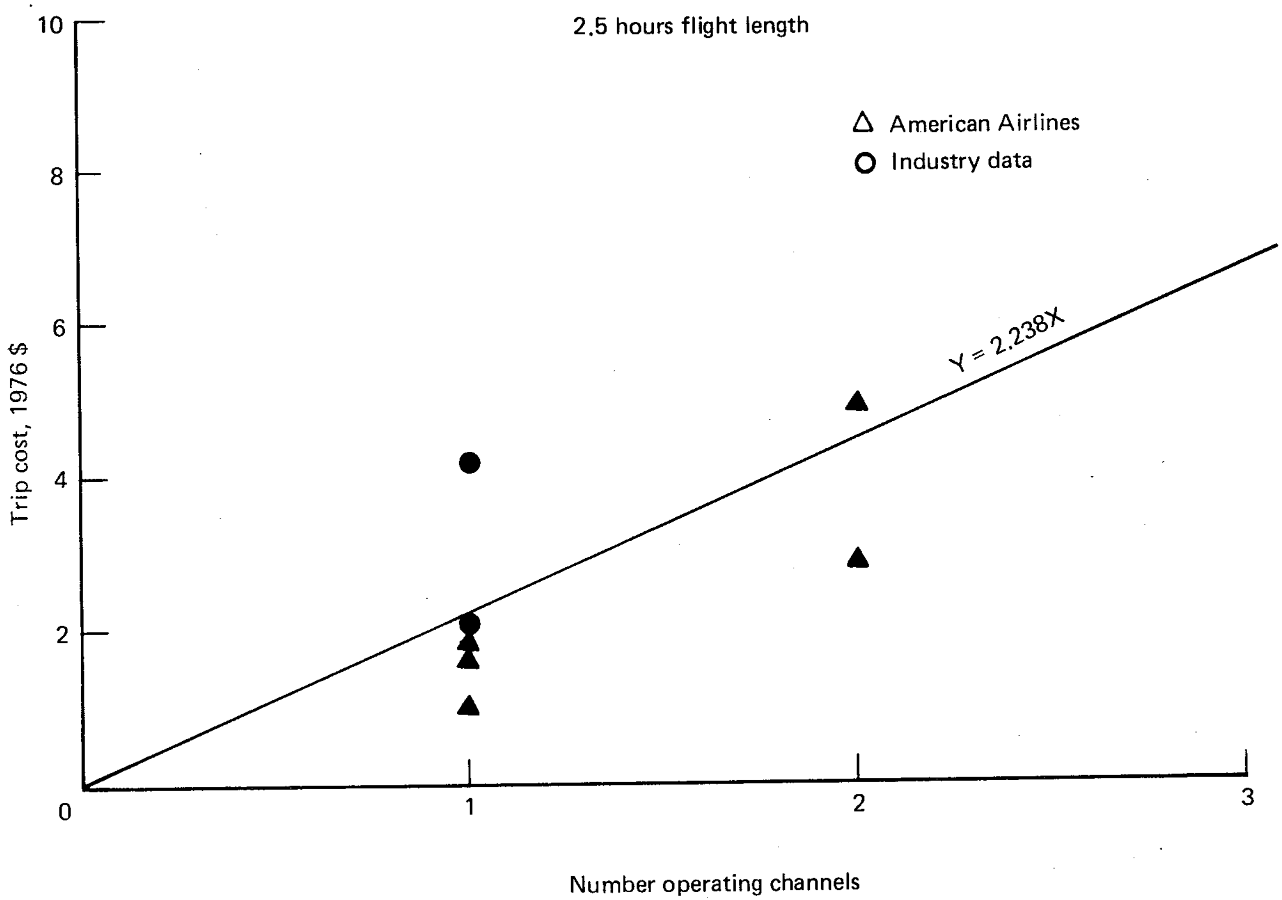

Figure 59.—ATA System 22—Auto-Flight—Labor

The 747 American Airline material point was excessively high, possibly as a result of the previously explained mischarges associated with the 747 airplane, and was neither plotted nor used in regressing the equation.

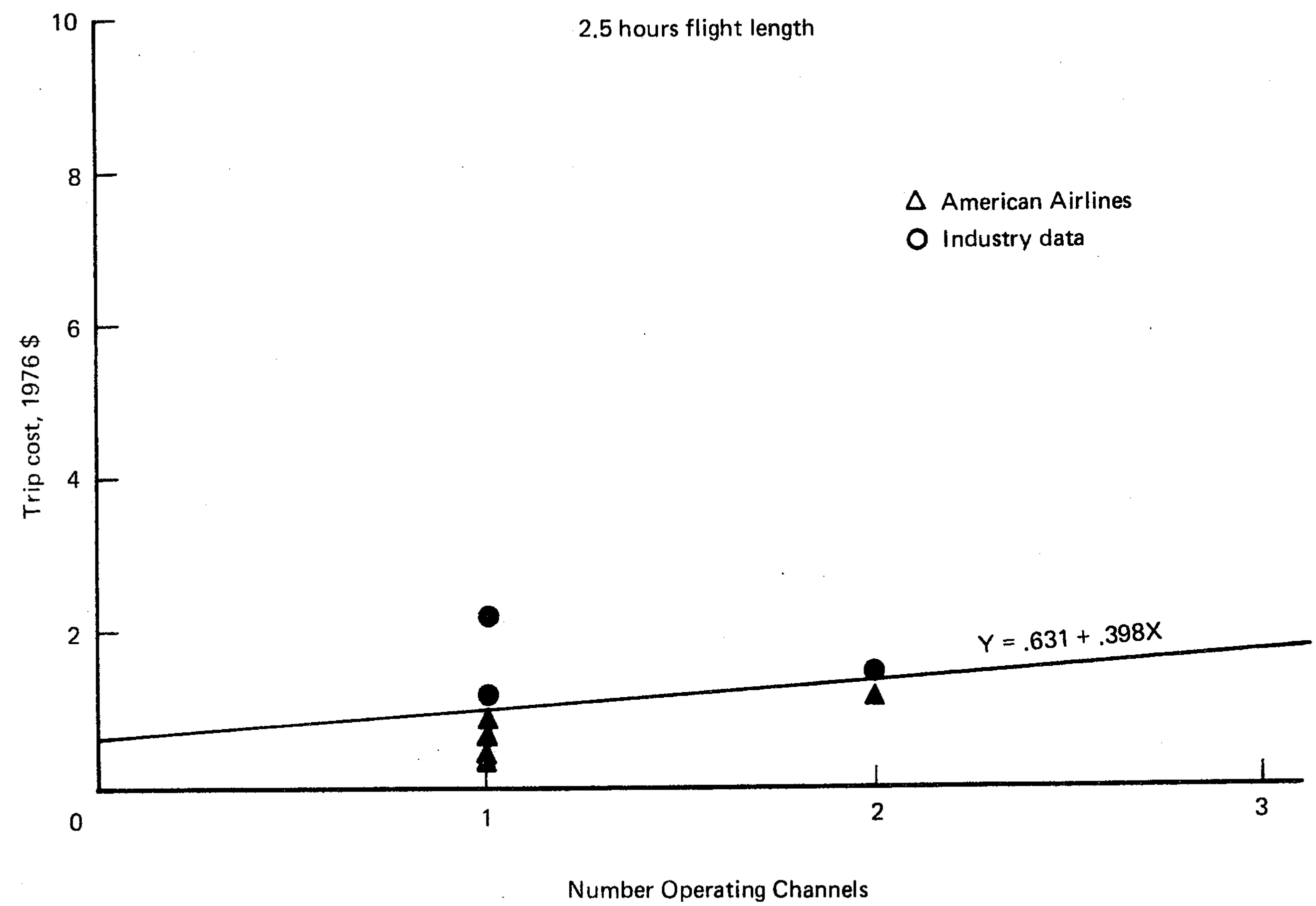

Figure 60.—ATA System 22—Auto-Flight—Material

The 747 American Airlines data points on all avionics systems including the 23 System were incorrect due to the previously explained mischarges and were neither plotted nor used. The lower curve reflects costs without the multiplex system (MUX) whereas the upper curve represents a system with MUX. In addition to direct costs associated with MUX components, the use of MUX is usually accompanied by a more complex entertainment system. Part of these costs also showed up in ATA System 23. An incremental cost for the MUX system was obtained from the Boeing experience retention data files and added to the lower curve at the 747 spec seat position on the abscissa to determine the upper curve.

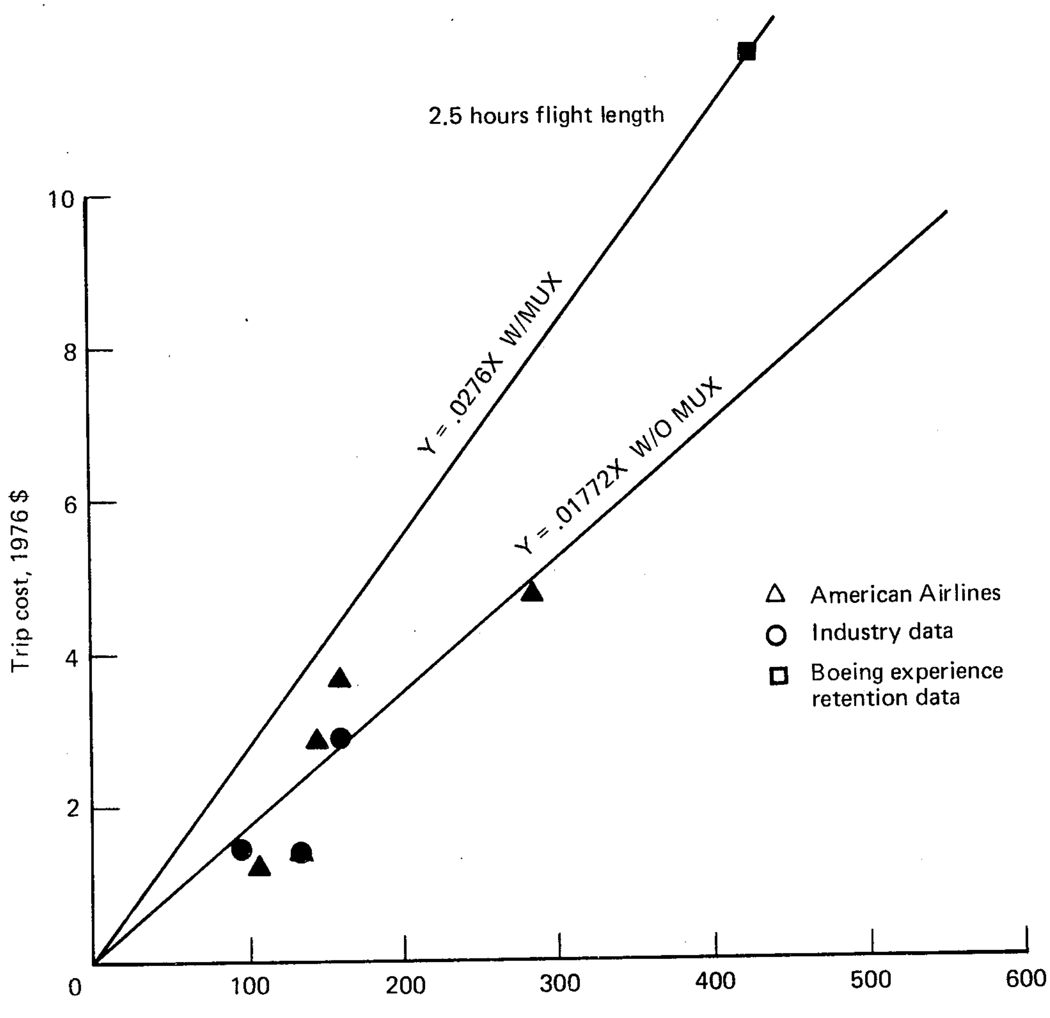

Figure 61.—ATA System 23—Communications—Labor

Comments similar to System 23 labor.

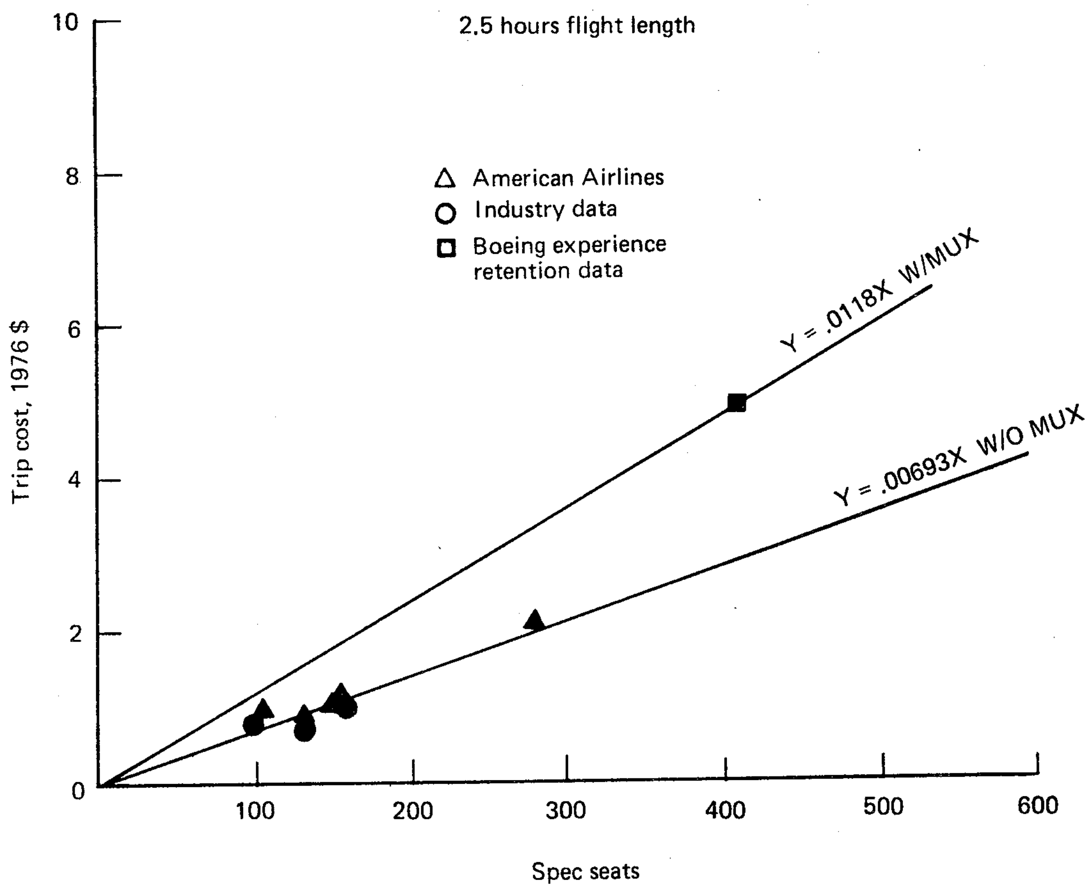

Figure 62.—ATA System 23—Communications—Material

Parameters tried included various combinations of standard and full time generators and their associated kVA ratings. The best regression using all American Airlines data points are the ones shown and utilized full time generators only. The industry source data is shown for comparison, but not used in this regression of labor costs due to inclusion of 99 System costs.

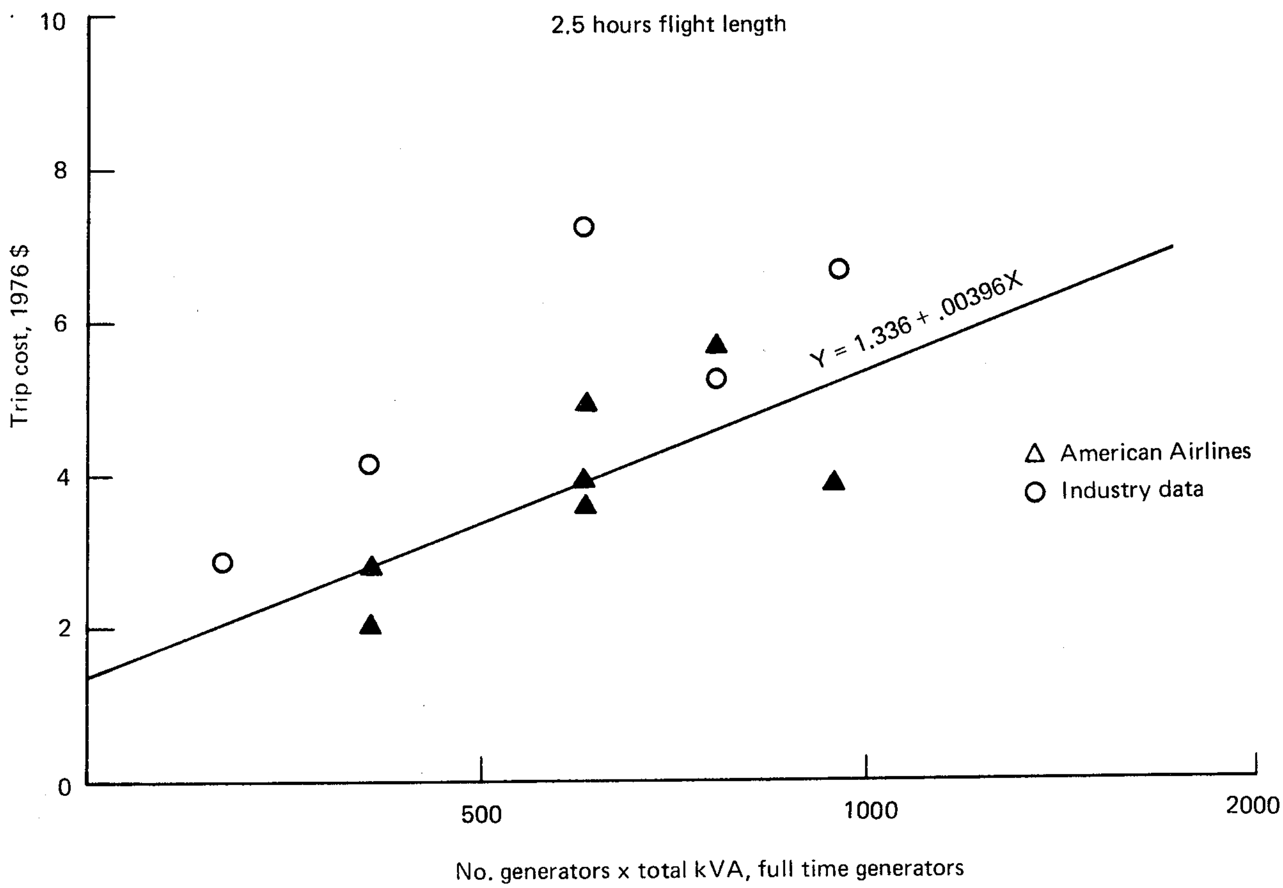

Figure 63.—ATA System 24—Electrical Power—Labor

All American Airlines and industry source data points are used in this regression to provide better averages of the somewhat diverging wide body points.

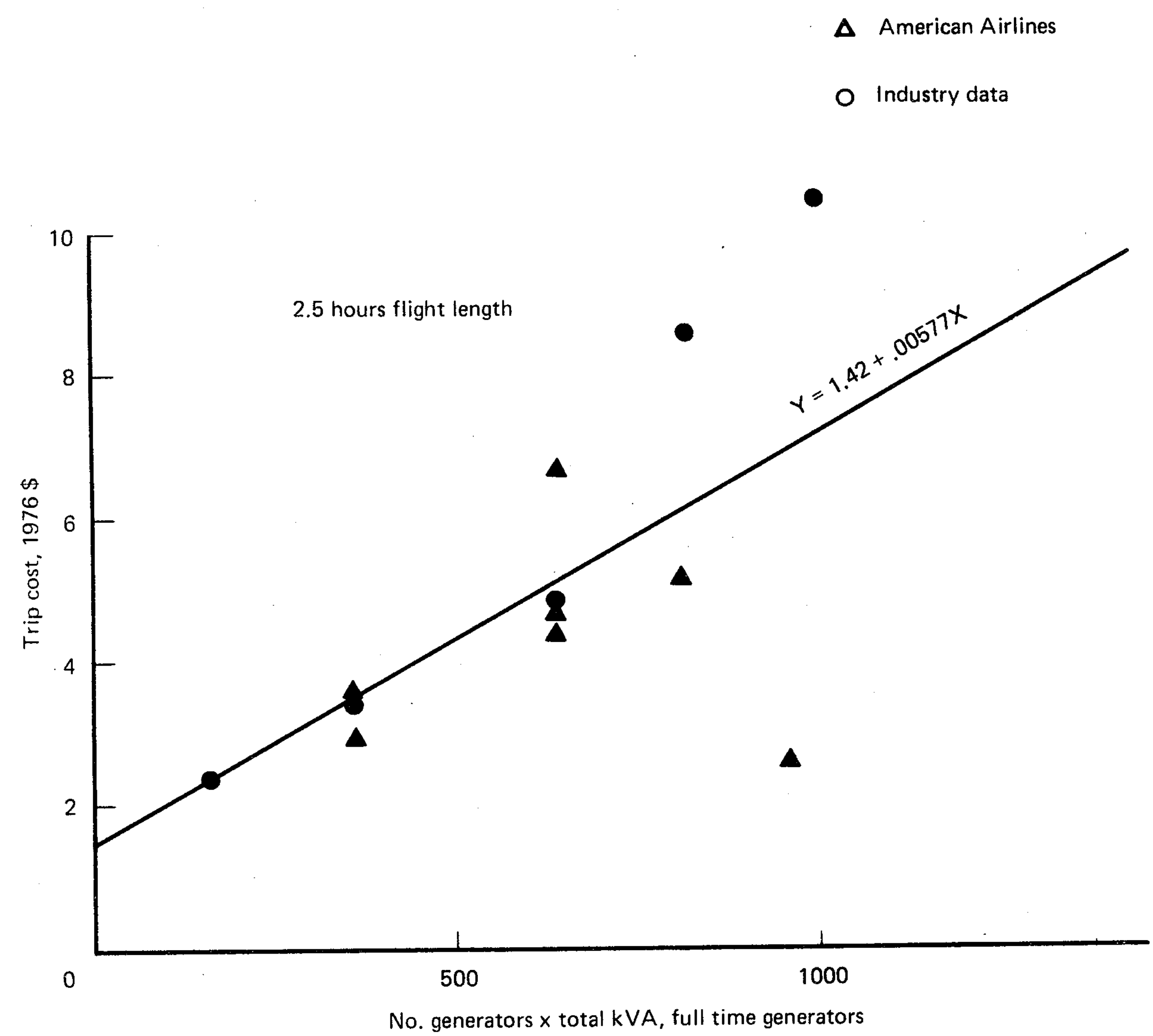

Figure 64.—ATA System 24 Electrical Power—Material

All American Airlines and industry source data points were used in this regression except for the AAL 747 data point. Refer to detailed write-up on this system. (Example calculations, paragraph 4.4.6.8.)

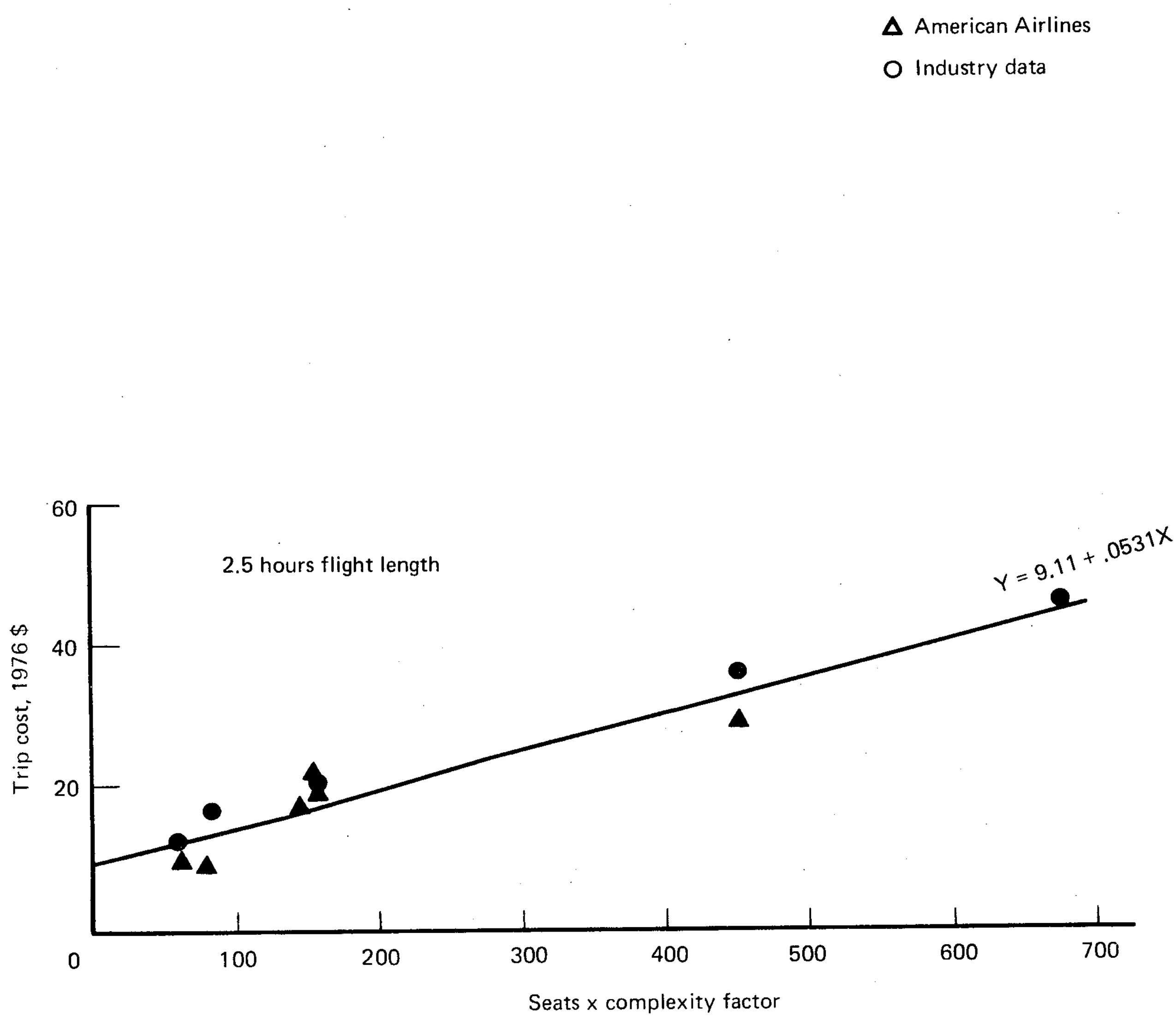

Figure 65.—ATA System 25—Equipment/Furnishing—Labor

Comments similar to System 25 Labor.

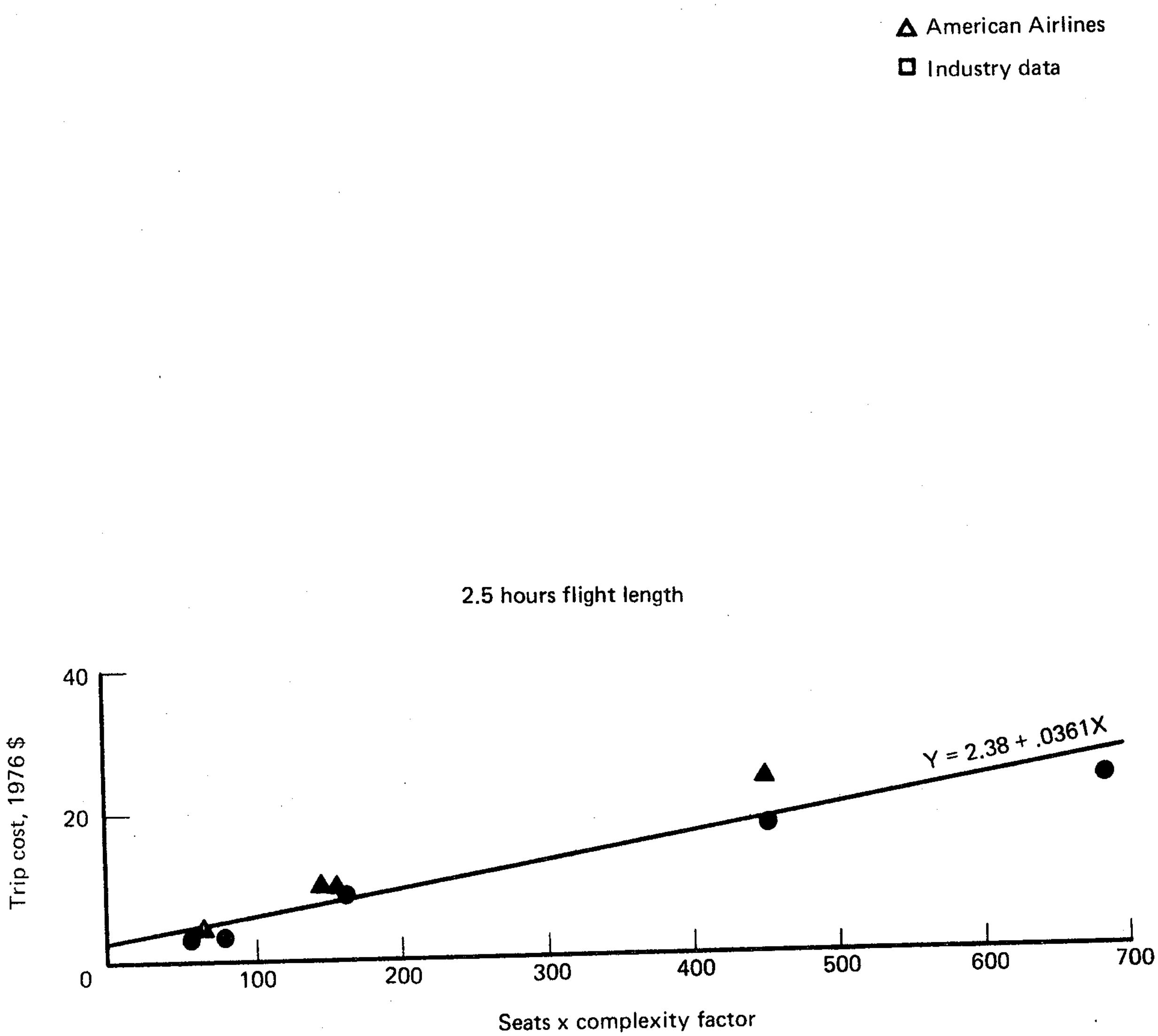

Figure 66.—ATA System 25—Equipment/Furnishing—Material

The majority of the costs in the ATA system are associated with the fire detection elements on the airplane and APU power plants. The baseline curve represents a system utilizing single circuit elements. All AAL and industry source data points except the 747 and DC-10 were used in the regression of the baseline curve. Both the 747 and DC-10 airplanes utilize dual circuits and all AAL and industry source 747 and DC-10 data points were used in the regression of the curve reflecting the total ATA 26 System costs for dual circuit installations. Other parameters tried included physical engine size and engine thrust.

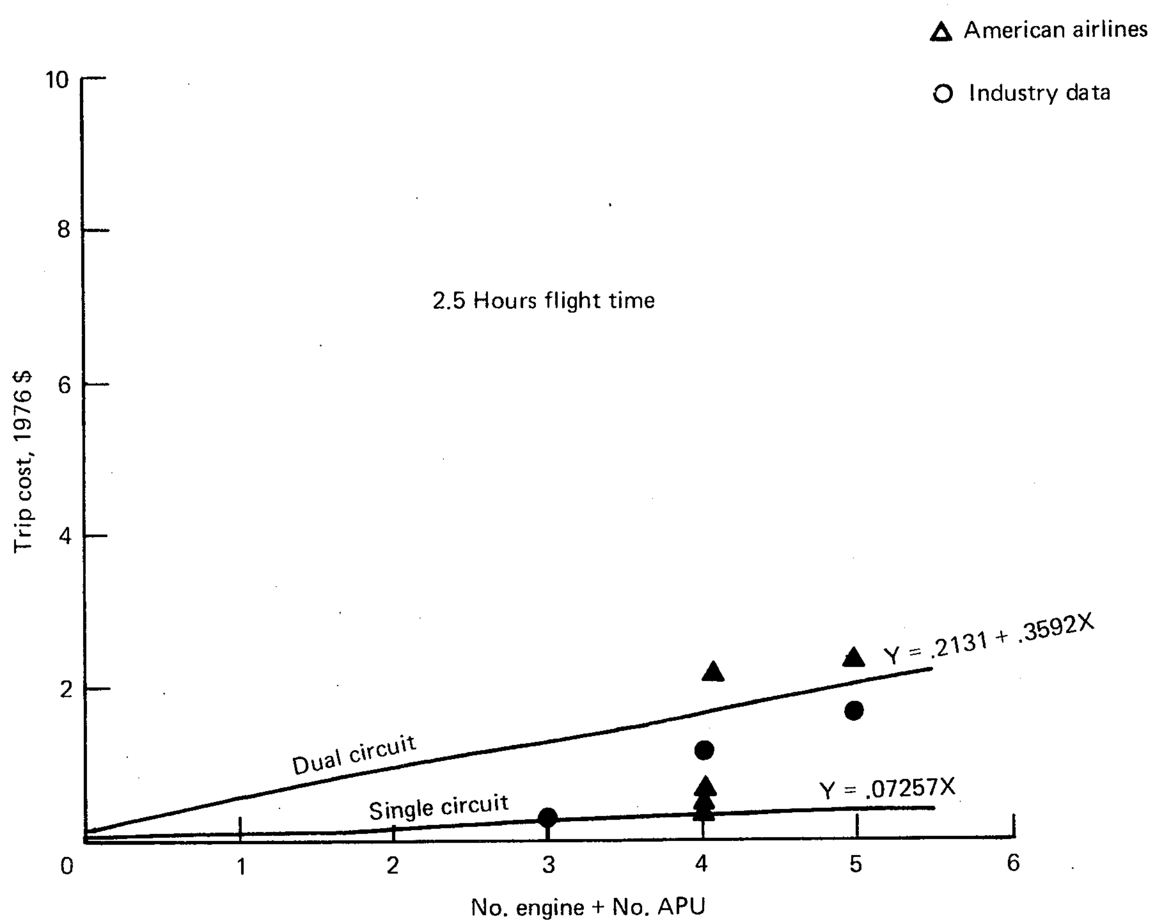

Figure 67.—ATA System 26 Fire Protection—Labor

Comments similar to System 26 Labor.

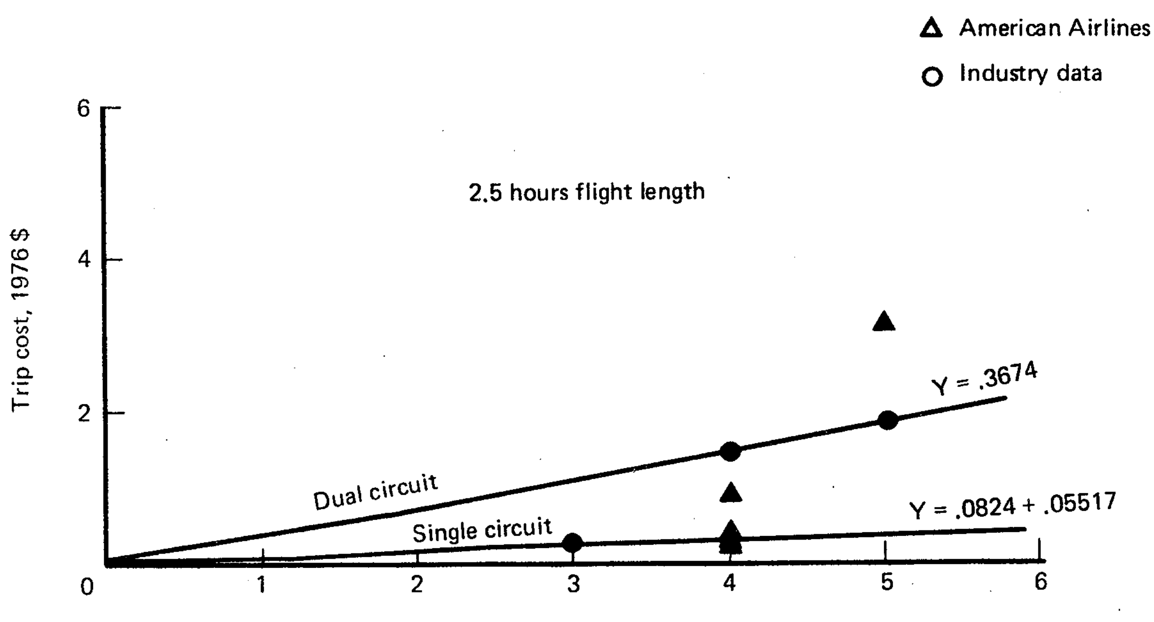

Figure 68.—ATA System 26—Fire Protection—Material

All American Airlines and industry source data points were used. Various airplane size related parameters were tried. The costs appeared to be little related to size, irrespective of the fact that larger airplanes have more and larger flight control components. One possible explanation is that the larger airplanes represent the newer technology, with improved reliability offsetting the increased size and complexity.

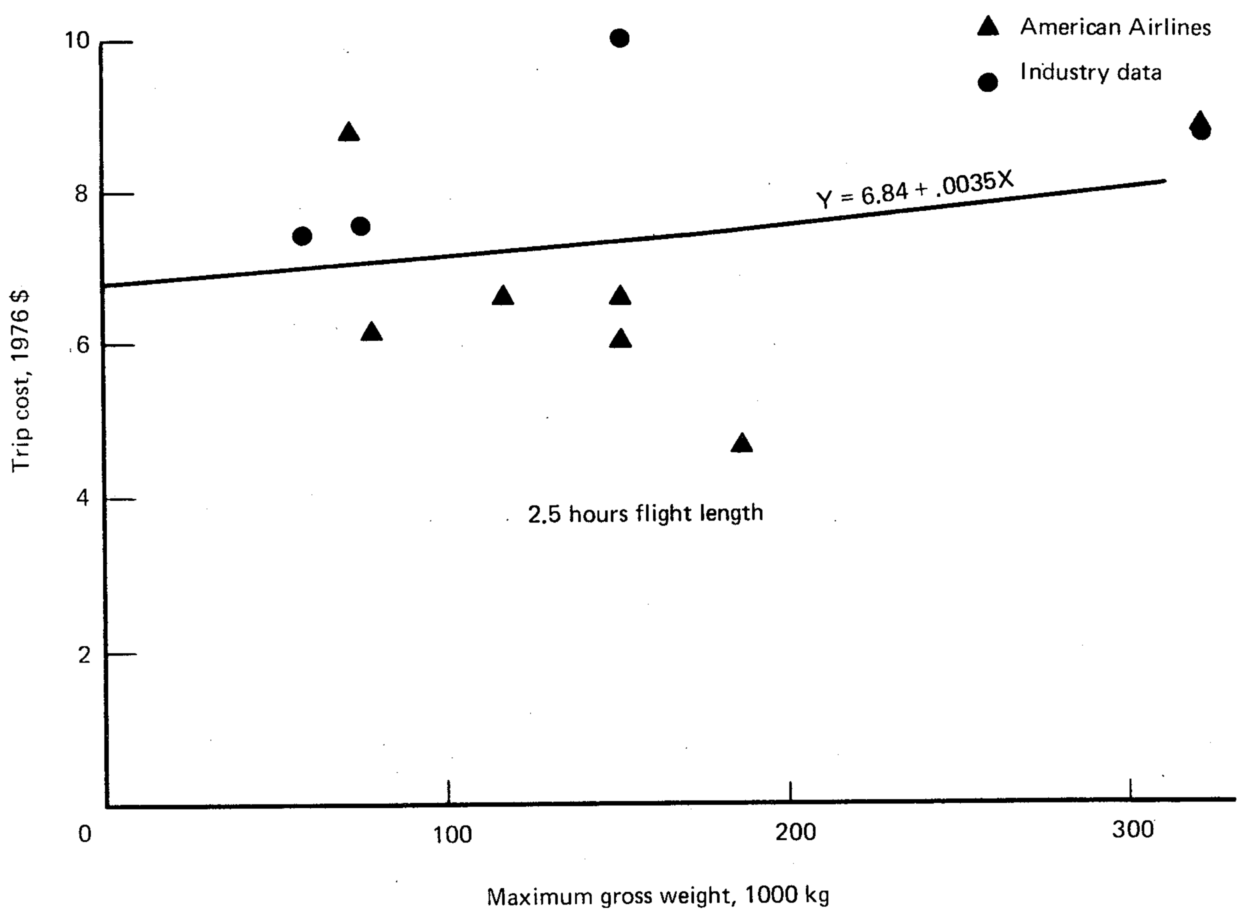

Figure 69.—ATA System 27—Flight Controls—Labor

Comments similar to System 27 Labor.

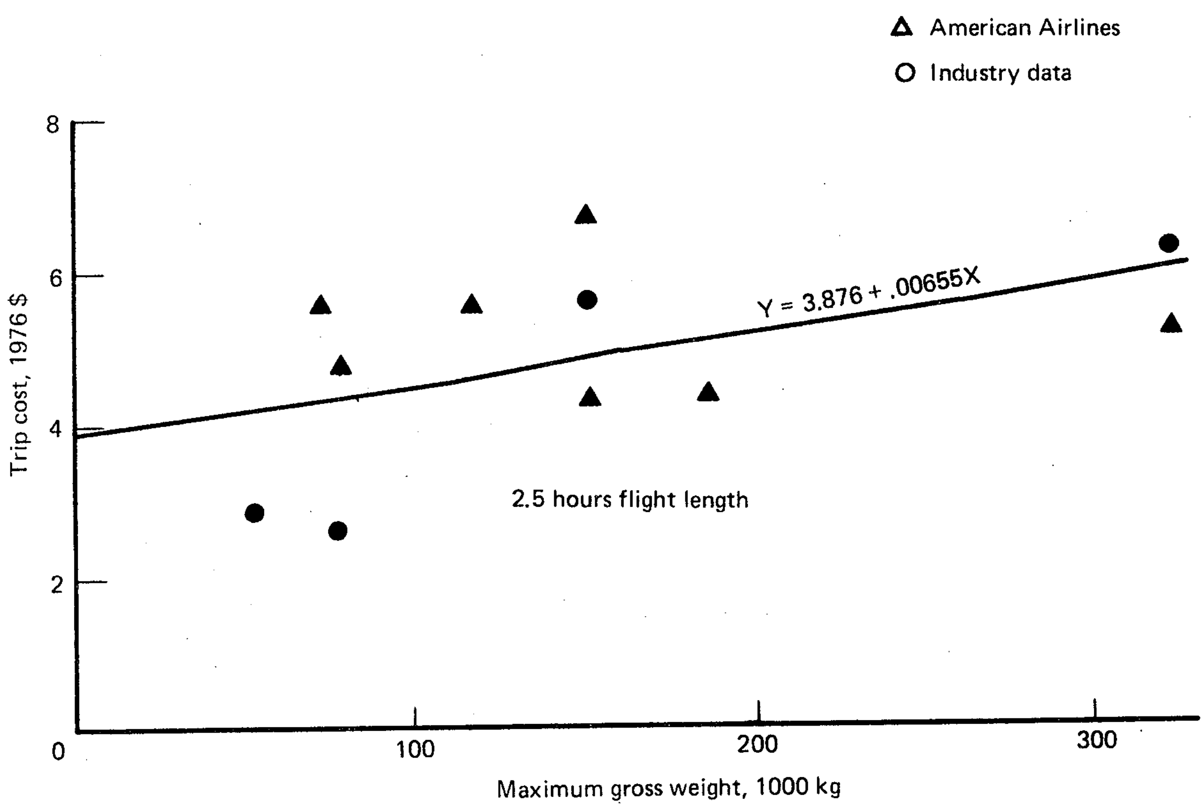

Figure 70.—ATA System 27—Flight Controls—Material

All American Airlines and industry source data points used. Other parameters tried for this system included design range and airplane weight.

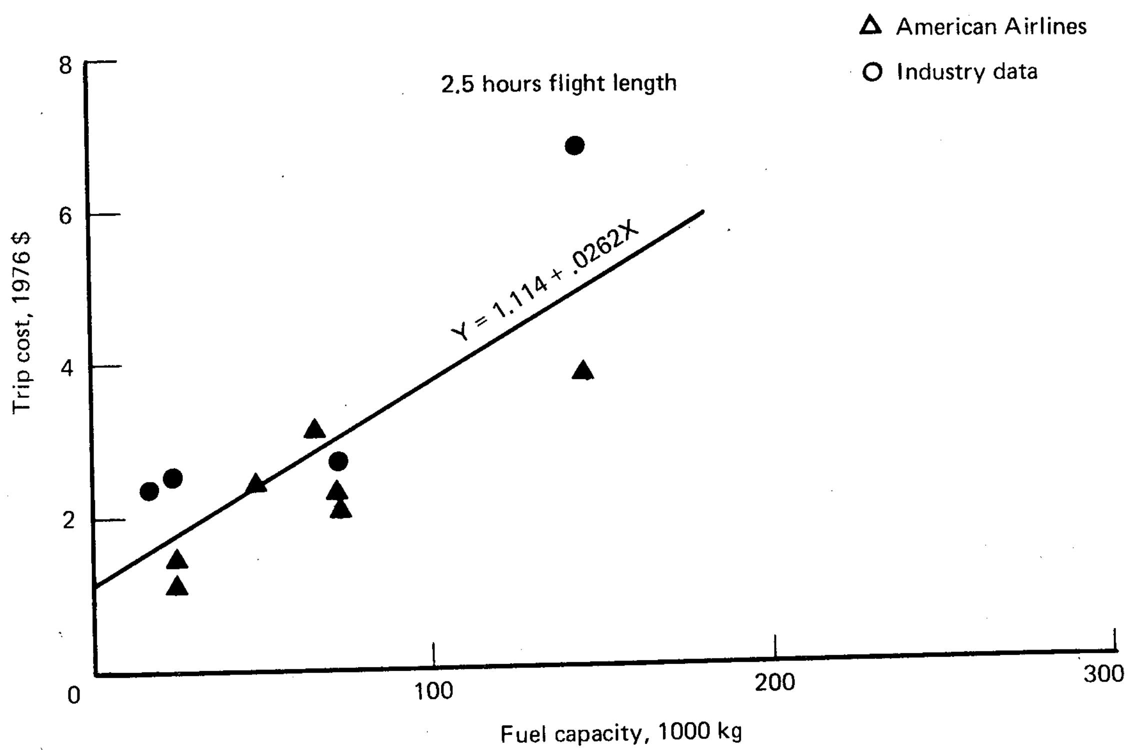

Figure 71.—ATA System 28—Fuel—Labor

Comments similar to System 28 Labor.

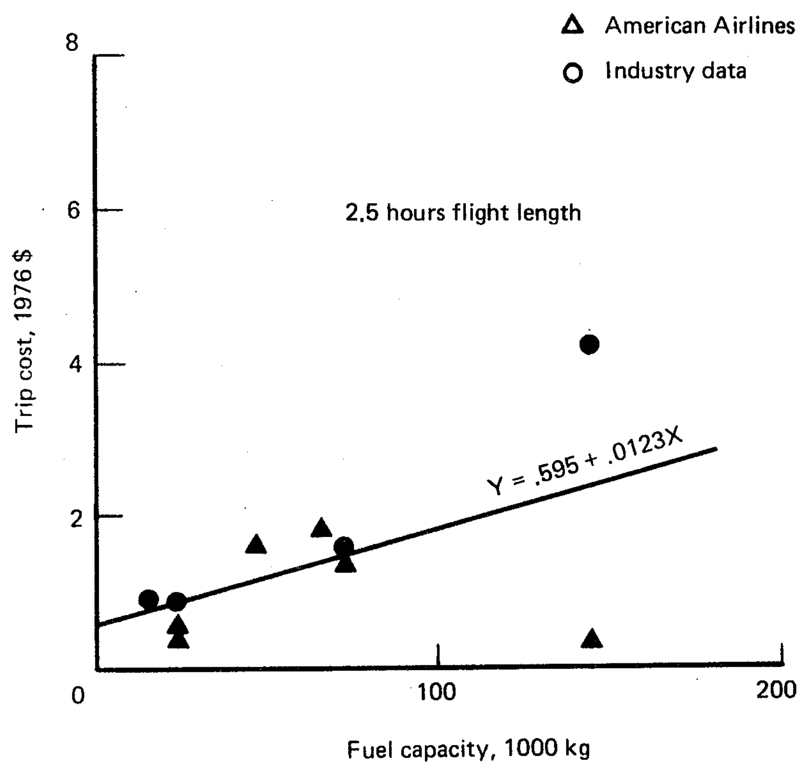

Figure 72.—ATA System 28—Fuel—Material

All American and industry source data points were used. Other parameters tried included various combinations of numbers of hydraulic systems, numbers of pumps (standby, demand, and full time) and pump capacity. The best regression was achieved by using continuously operated pumps only, without any air drivers or standby pumps.

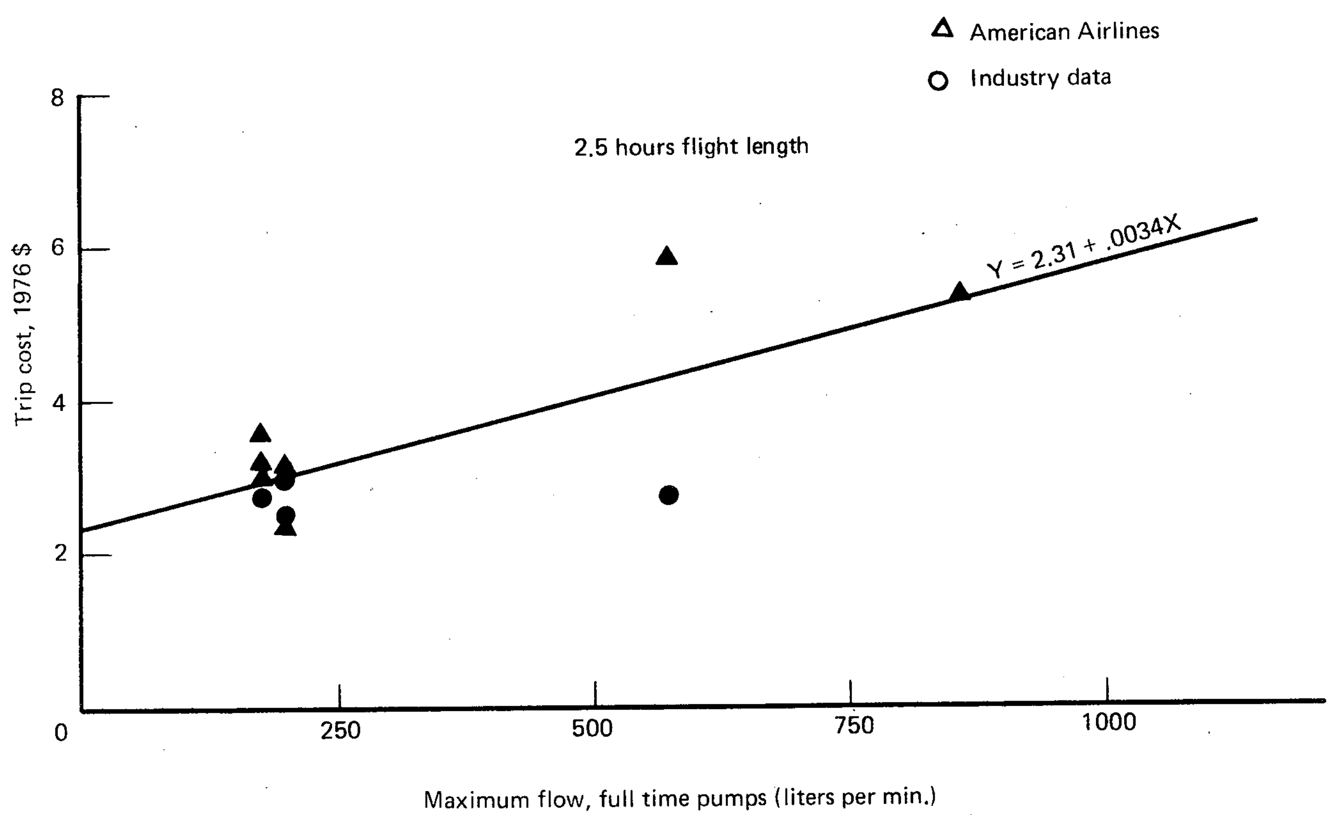

Figure 73.—ATA System 29—Hydraulic Power—Labor

Comments similar to System 29 Labor.

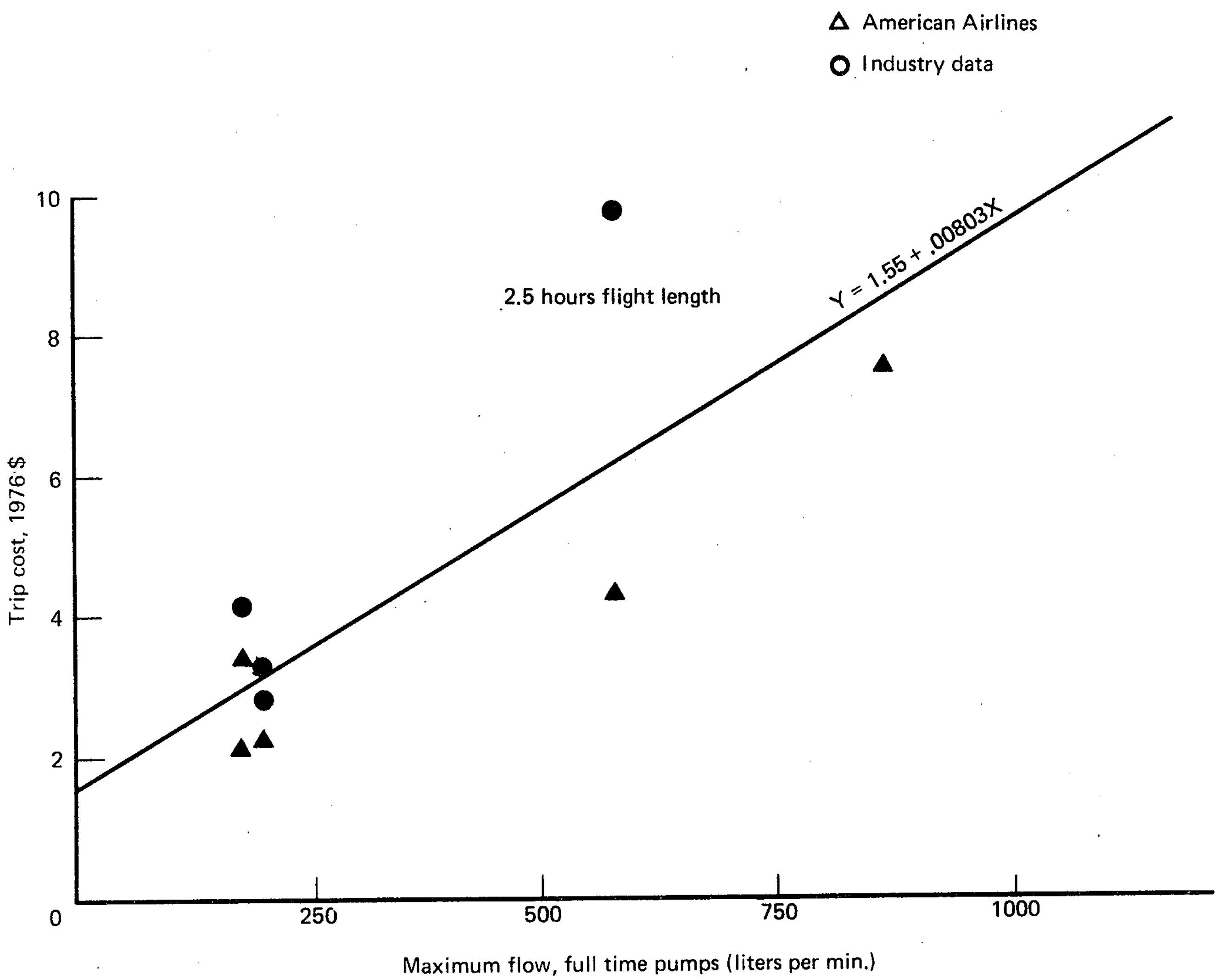

Figure 74.—ATA System 29—Hydraulic Power—Material

Costs are relatively small and very nearly constant in nature. All AAL and industry source data points were used in the regression.

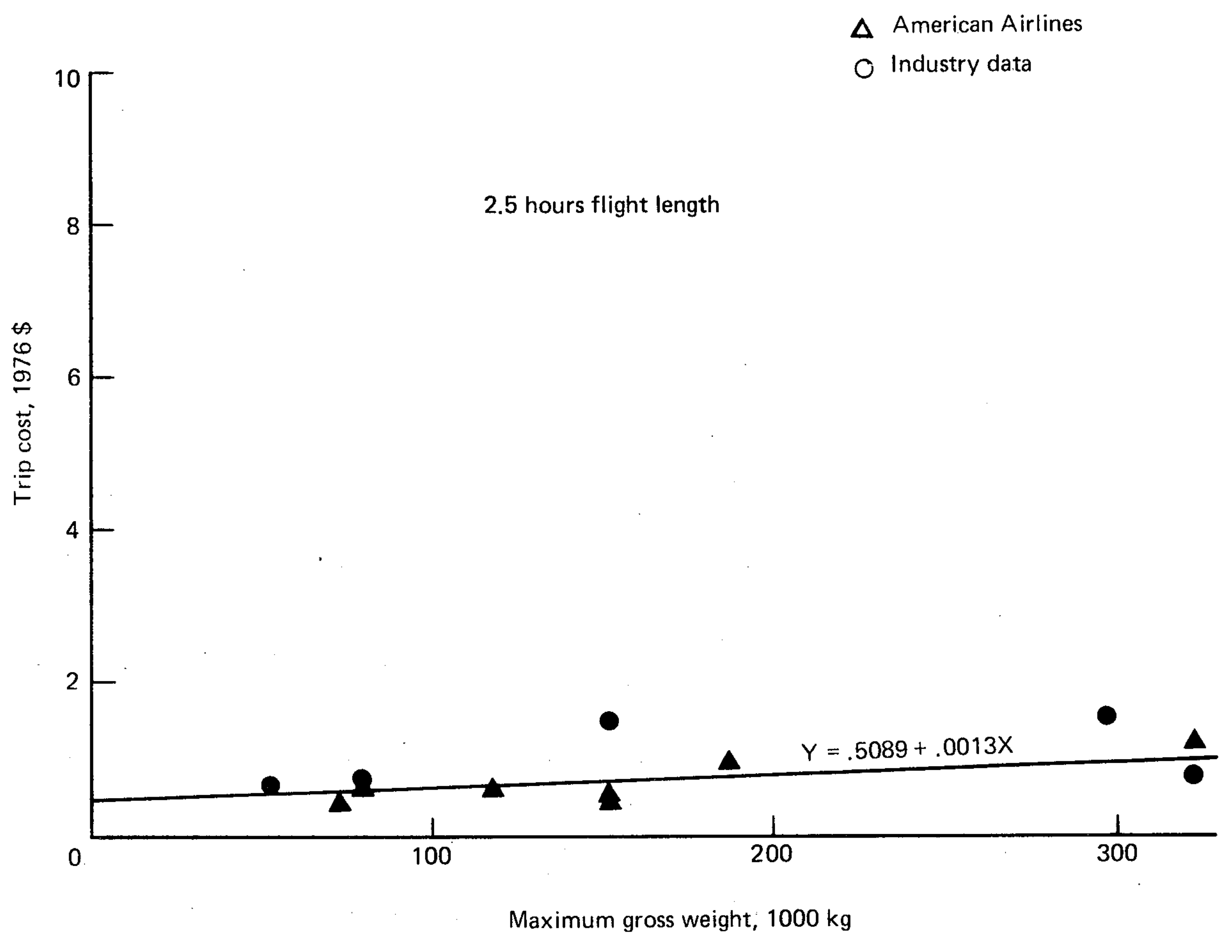

Figure 75.—ATA System 30—Ice/Rain Protection—Labor

Comments similar to System 30 Labor.

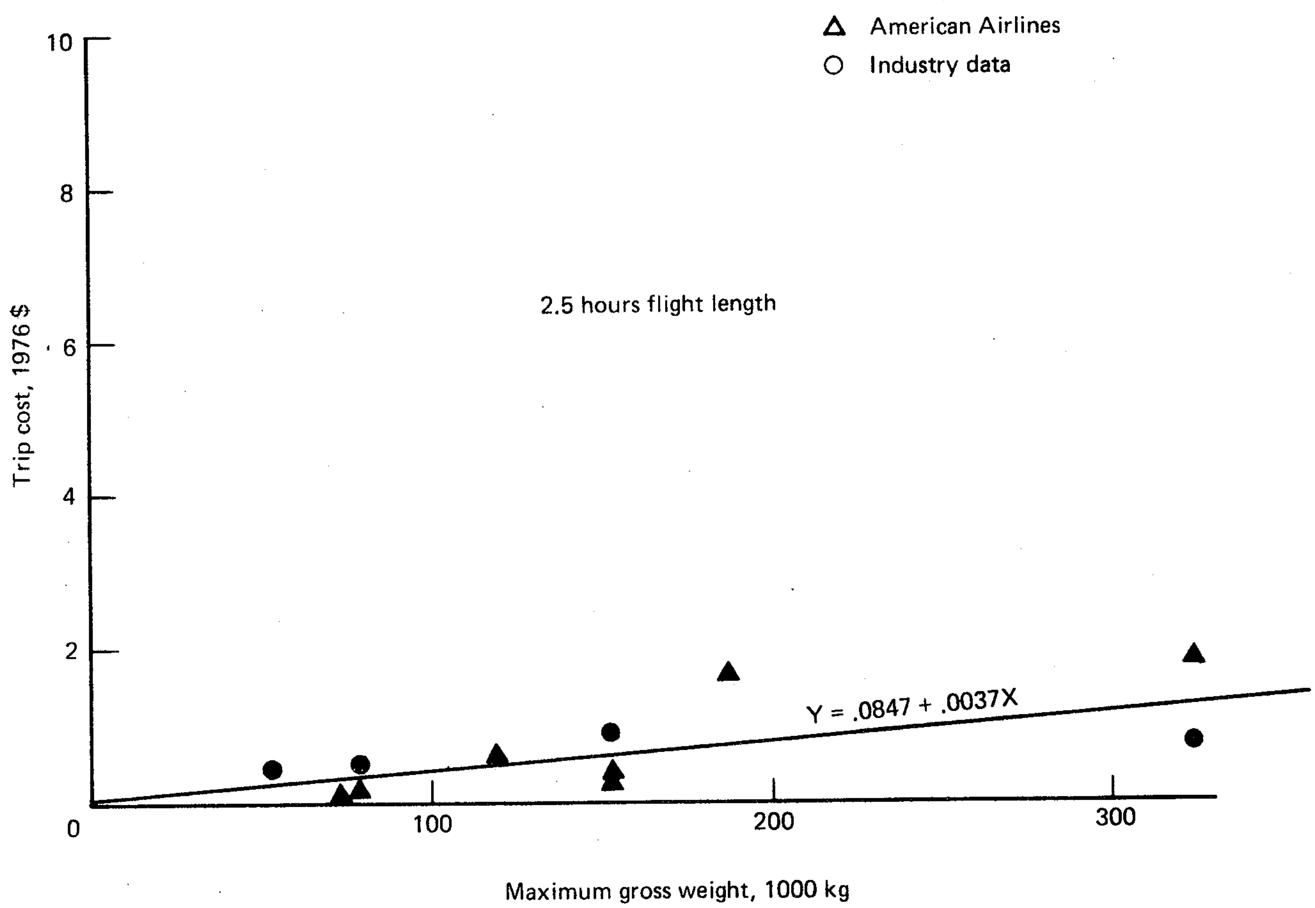

Figure 76.—ATA System 30—Ice/Rain Protection—Material

This system contains only a few instruments as the instruments associated with each ATA System are included within the various ATA Systems. The costs are constant in nature. Points not included in the regression are the industry source 707 points.

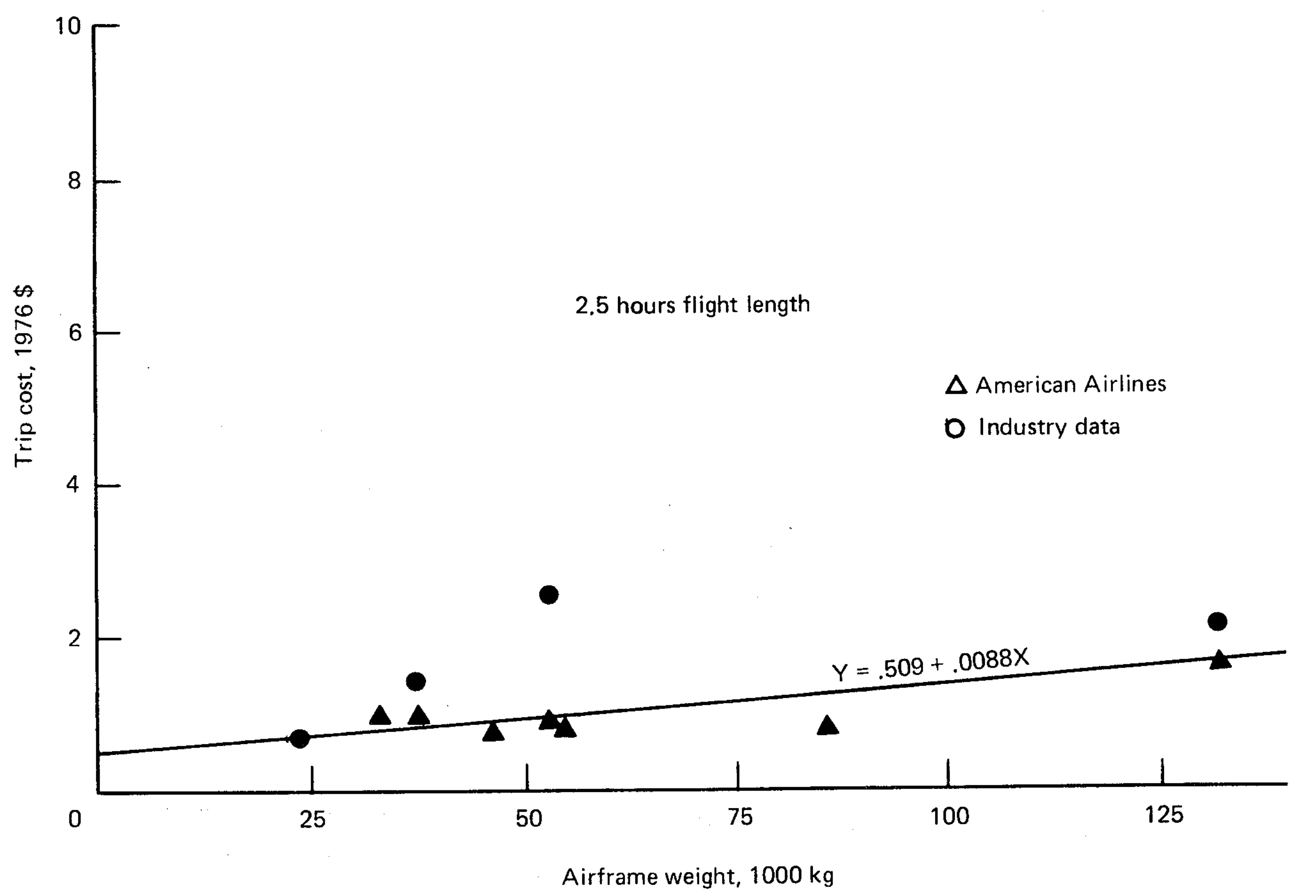

Figure 77.—ATA System 31—Instruments—Labor

Comments similar to System 31 Labor except that the AAL 747 point appeared to be incorrect and was excluded, whereas the industry source 707 point was used.

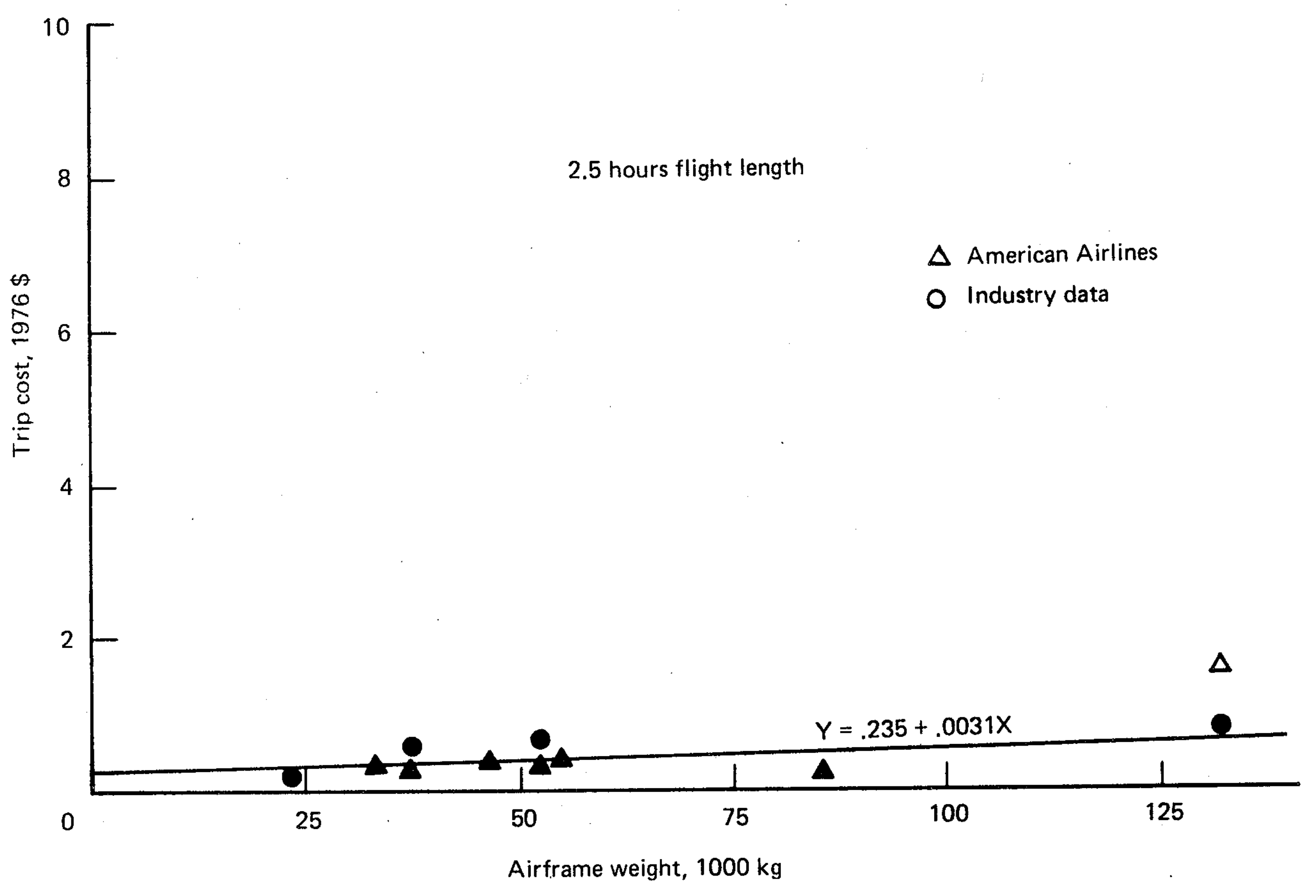

Figure 78.—ATA System 31—Instruments—Material

A number of parameters were tried on this system due to its relatively large cost impact on the total airplane. Parameters included various combinations of weight, kinetic landing energy, tire size, tire inflation and number of tires. In the process of exploring parameters it was discovered that AAL tire maintenance is contracted on a per-tire-landing basis for all airplane models. A plot of the AAL data points versus number of wheels reflected this condition by producing a good correlation. Since a per-tire-landing contract is not representative of the total airline industry, only industry source data points, including the DC-10 point which has been substantiated for this system, were used as the data base and plotted against the various parameters. It was anticipated that tire maintenance should be a function of maximum gross weight, whereas brakes maintenance should be a function of kinetic energy. However, good correlation was obtained using only maximum gross weight. Thus, in the 32 System charts the AAL data points are shown for reference but not used in the regression, the industry source data is regressed as a function of maximum gross weight for the total system.

Charts relating to brake kinetic energy versus cost and specific tire cost data relating to maximum gross weight are also provided to show the relationship between tire and brake costs within the industry. These are shown in figures 79, 80, 81, 84, 85, and 86. Figure 82 is for industry data and is illustrative of the division of costs between wheels and brakes.

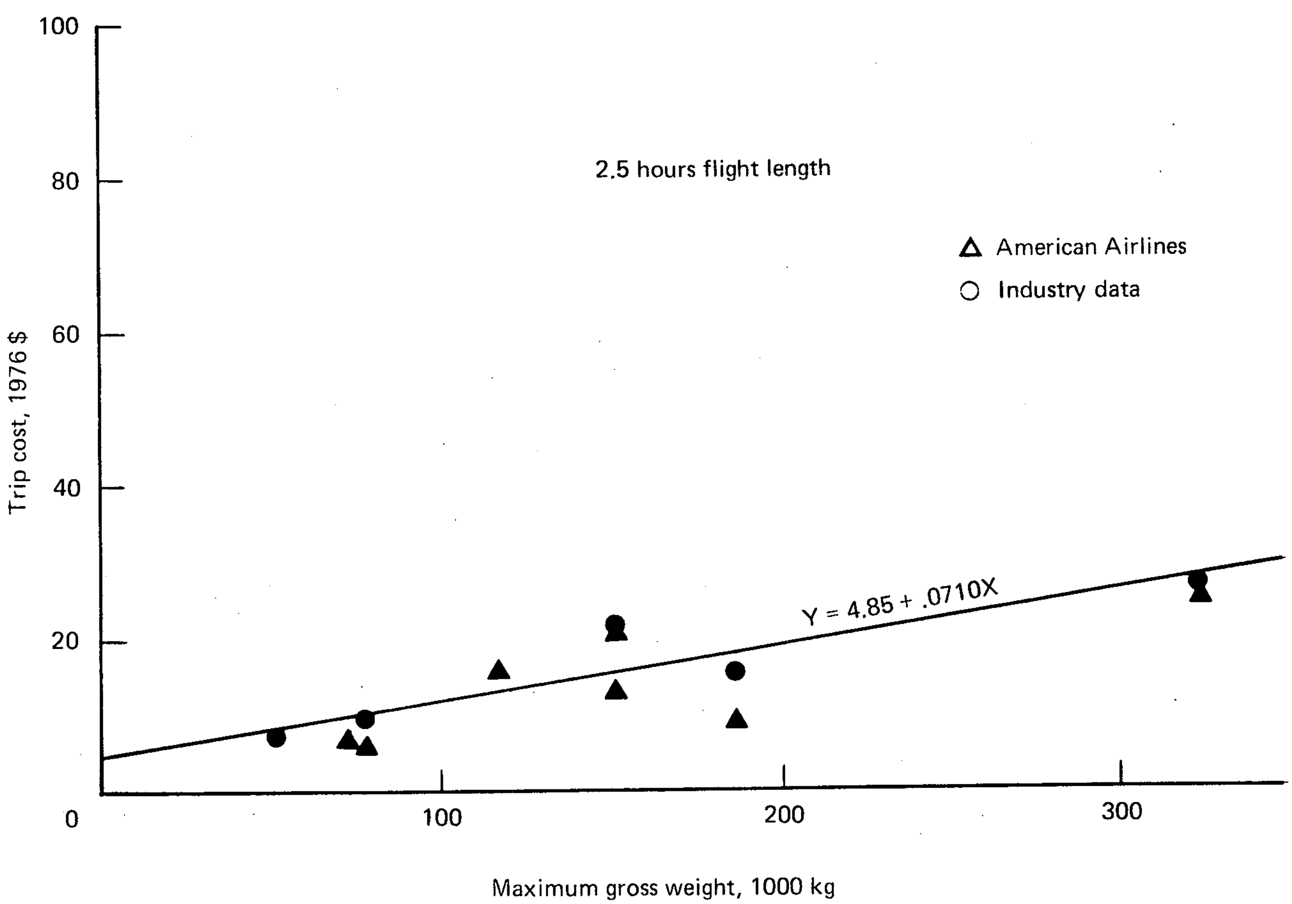

Figure 79.—ATA System 32—Landing Gear—Labor

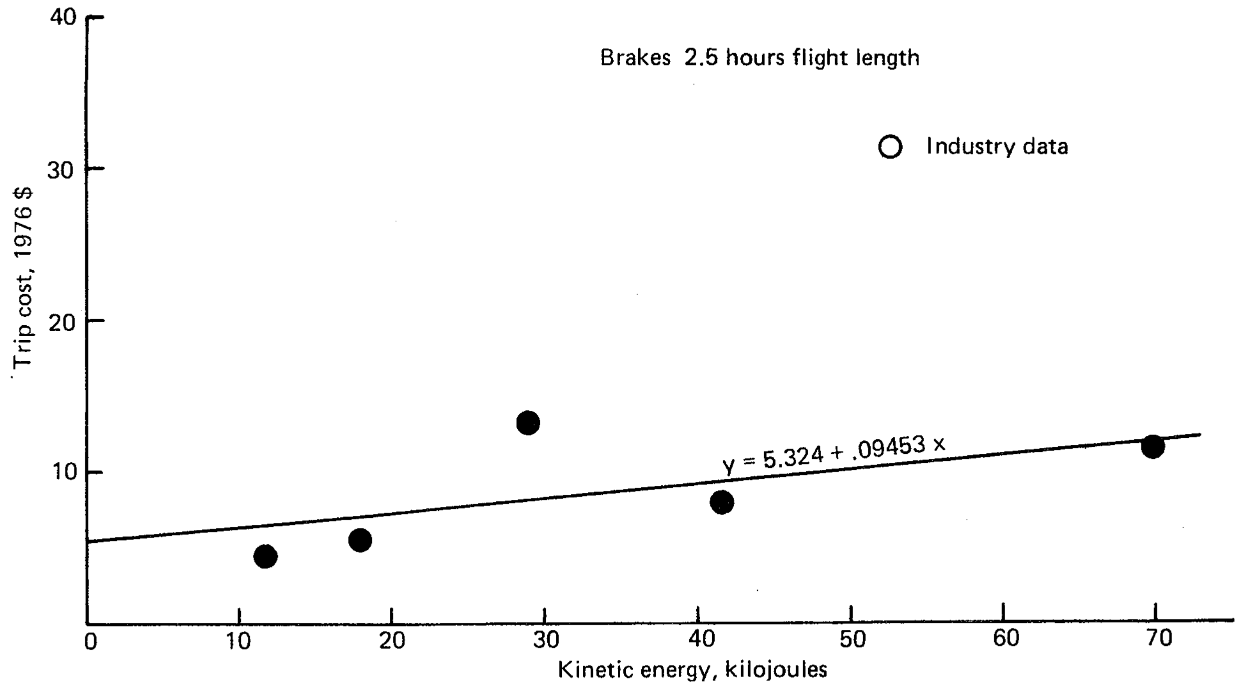

Figure 80.—ATA System 32—Landing Gear—Labor

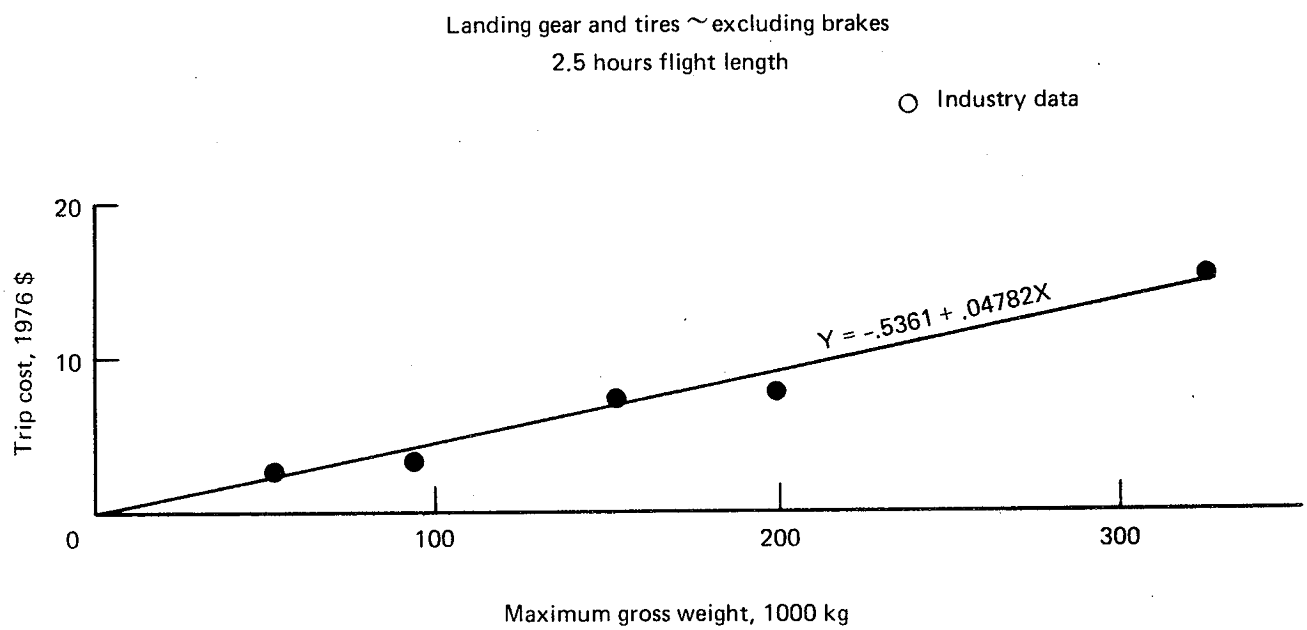

Figure 81.—ATA System 32—Landing Gear—Labor

Industry Data

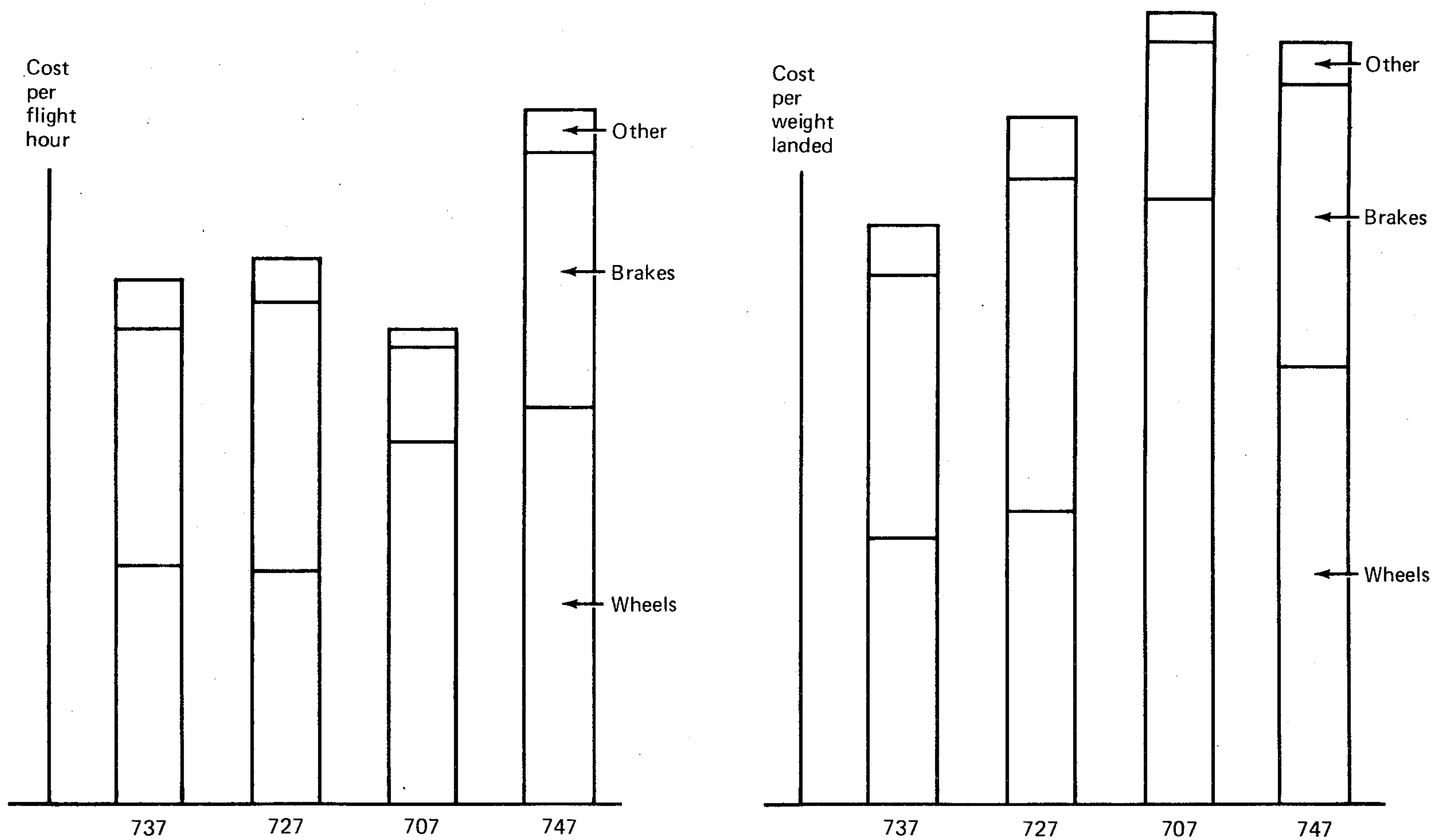

Figure 82.—ATA System 32—Landing Gear Maintenance

Industry Data

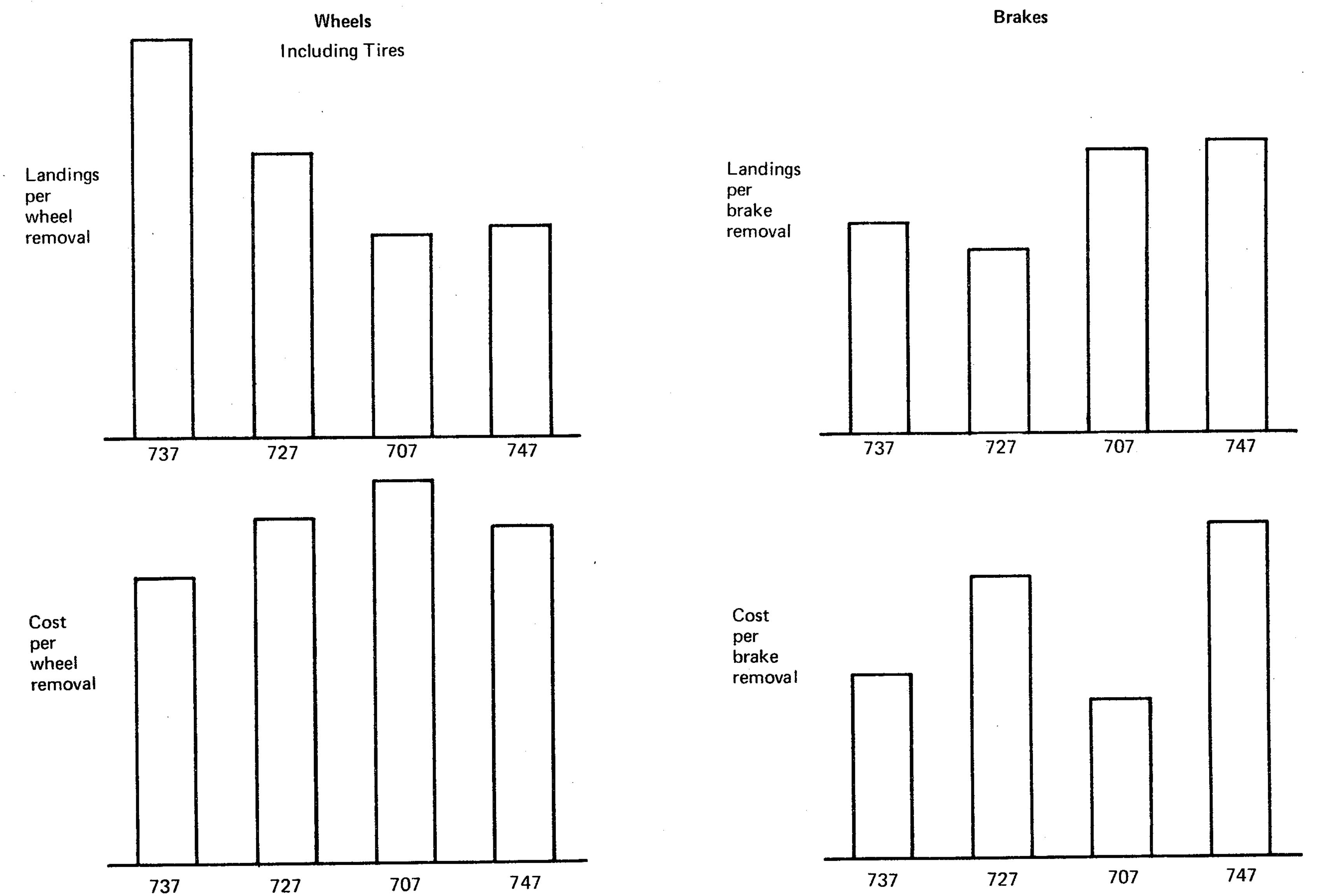

Figure 83.—Wheel and Brake Maintenance

Comments similar to System 32 Labor.

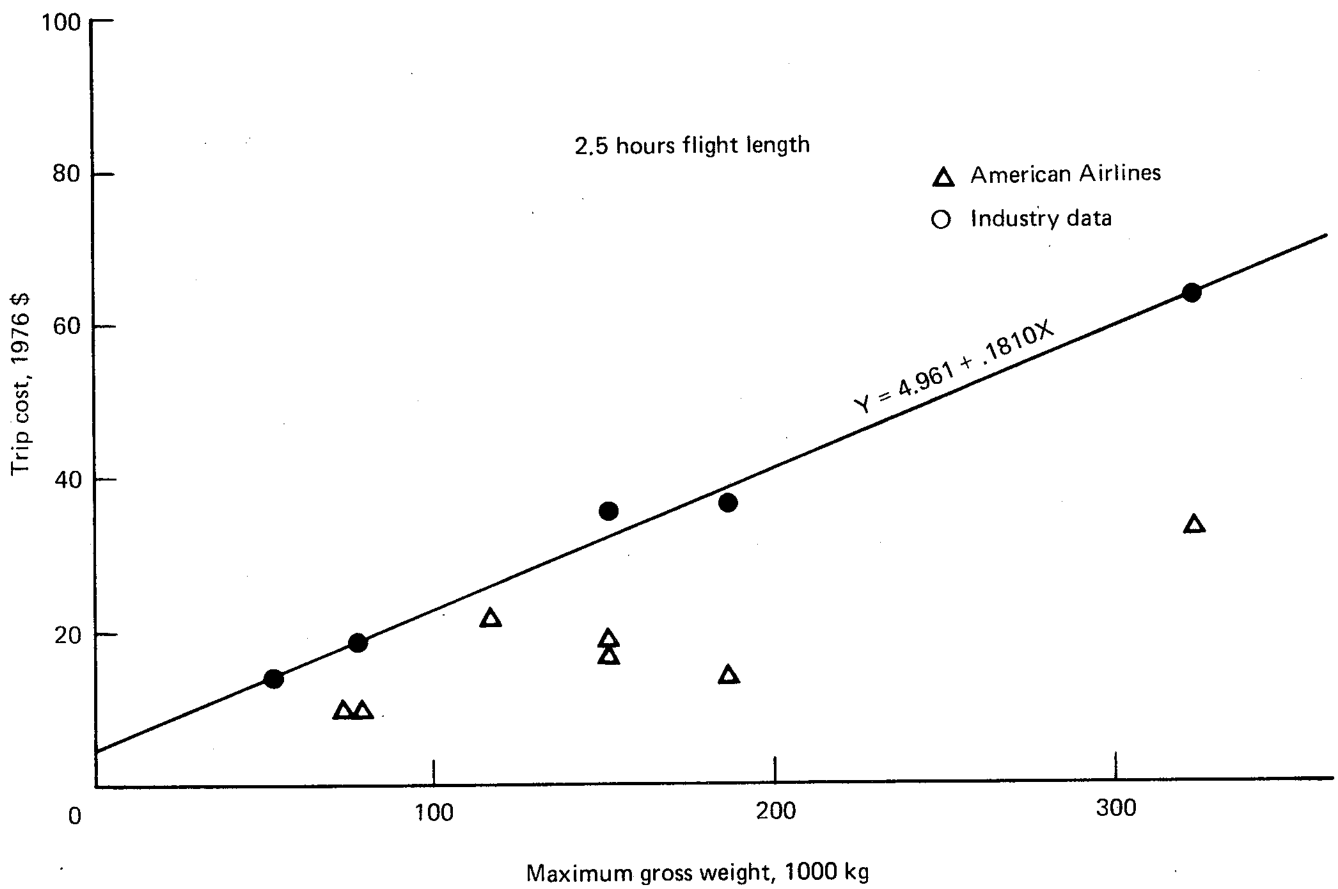

Figure 84.—ATA System 32—Landing Gear—Material

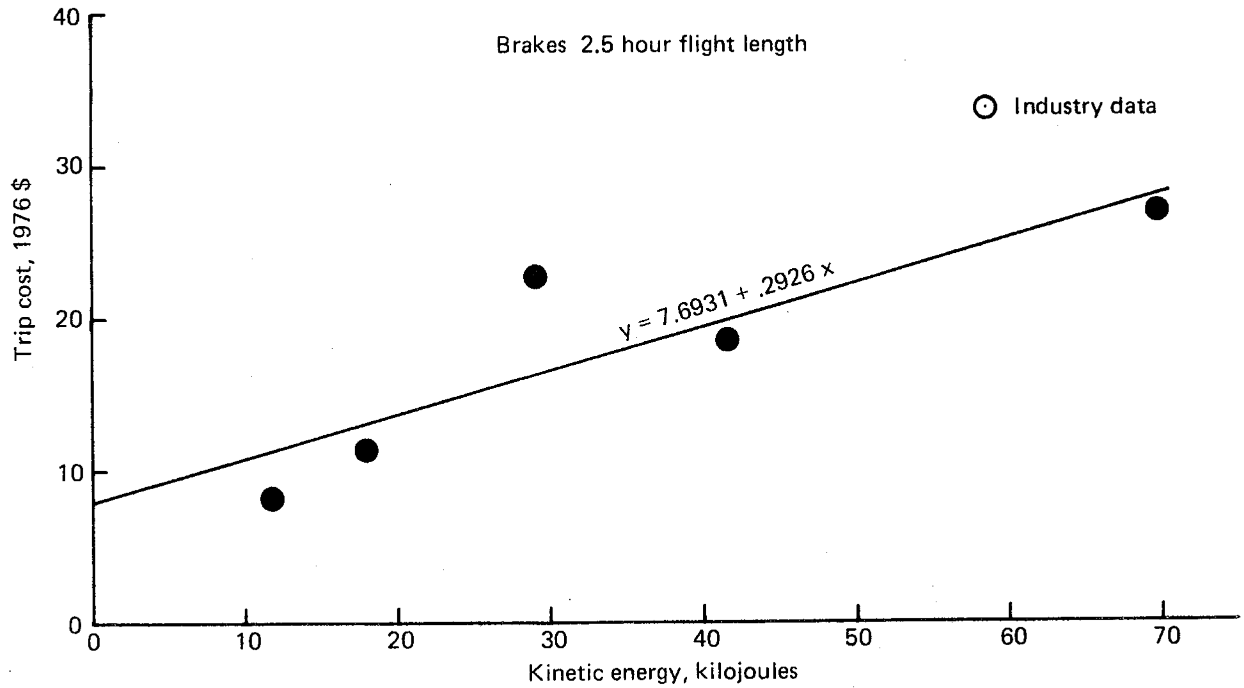

Figure 85.—ATA System 32—Landing Gear—Material

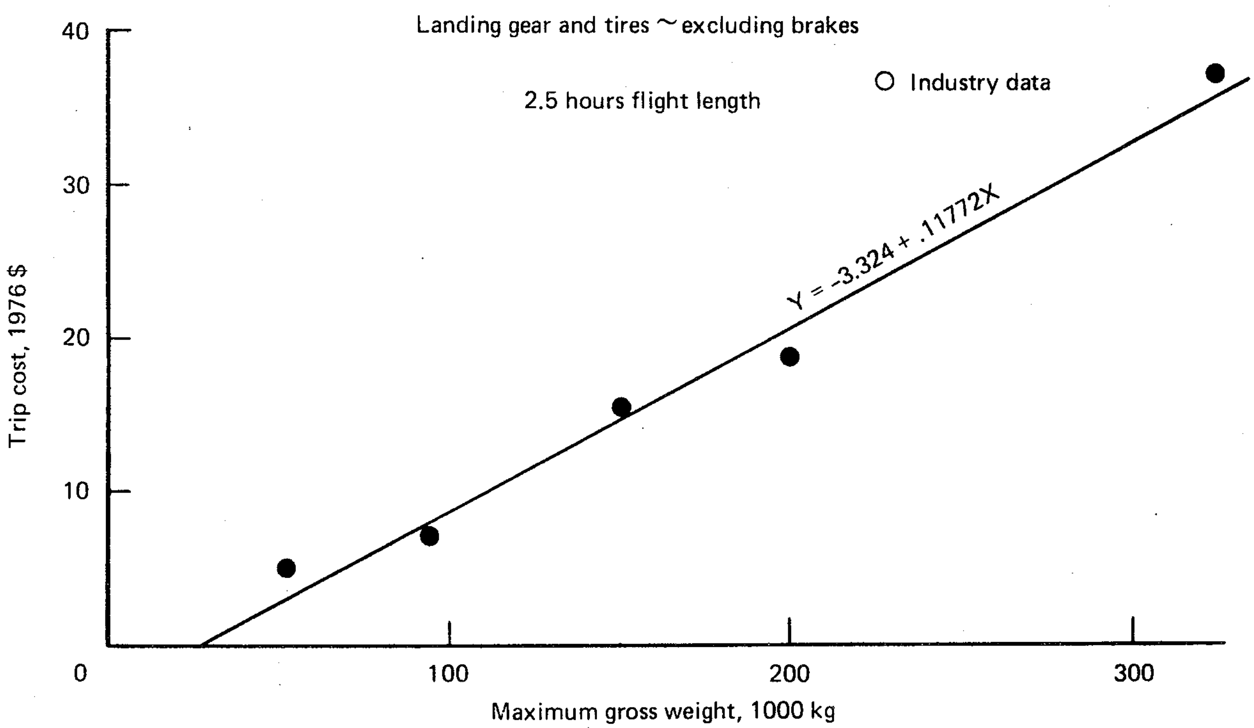

Figure 86.—ATA System 32—Landing Gear—Material

All data points were used in the regression of the labor except the American Airlines 747 point which was unusually high. Use of the complexity factor developed for ATA System 25 improved the regression as compared with using only spec seats. This was to be expected since a more complex equipment and furnishing system (System 25) usually results in a more complex interior lighting system.

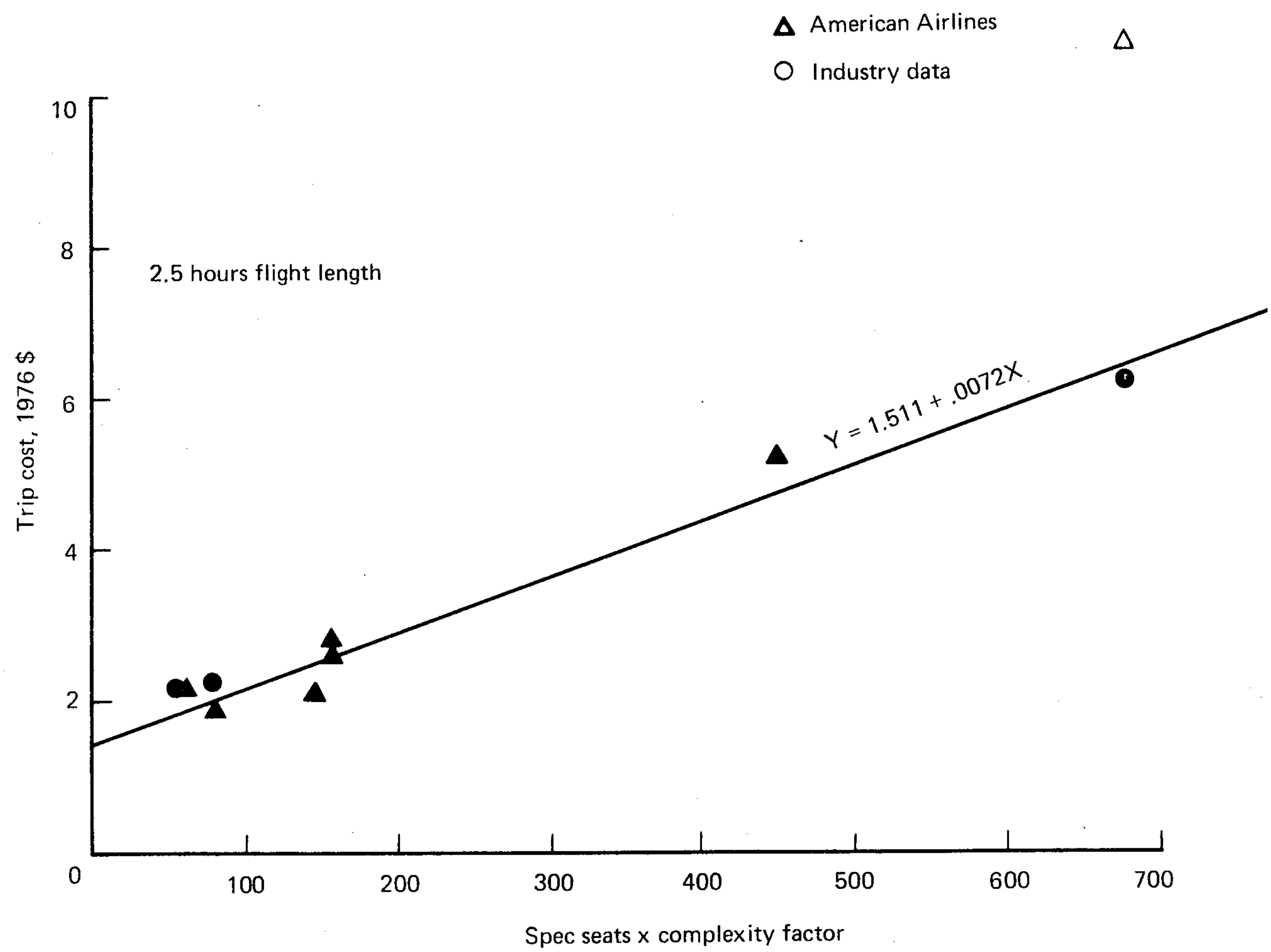

Figure 87.—ATA System 33—Lighting—Labor

All data points were used in the regression. The complexity factor in combination with spec seats provided the best correlation.

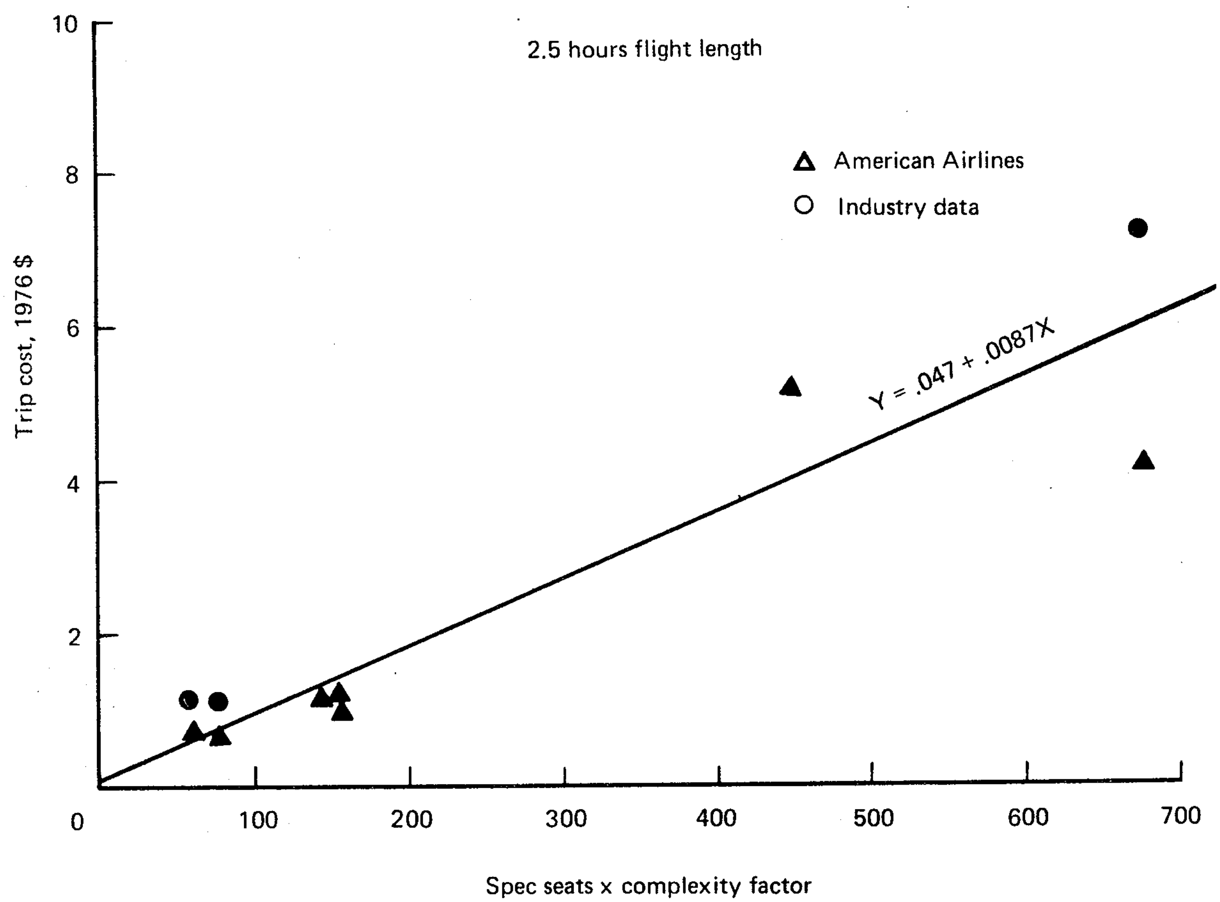

Figure 88.—ATA System 33—Lighting—Material

All data points were used except the AAL 747 point which has been excluded from all avionic systems due to improper data and the 707 industry source data point which represented older technology. Regression of the retained points produced the lower curve which is a system without INS (inertial navigation system). The incremental costs for the installation of a single INS were determined for Boeing experience retention data sources and added to the lower curve to develop the upper curve.

Other parameters relating to airplane size were tried but considered illogical as a parameter for navigation. Recognizing that longer range airplanes generally have more complex navigation systems, the design complexity factor used on the other ATA systems was again used with relatively good success on this system.

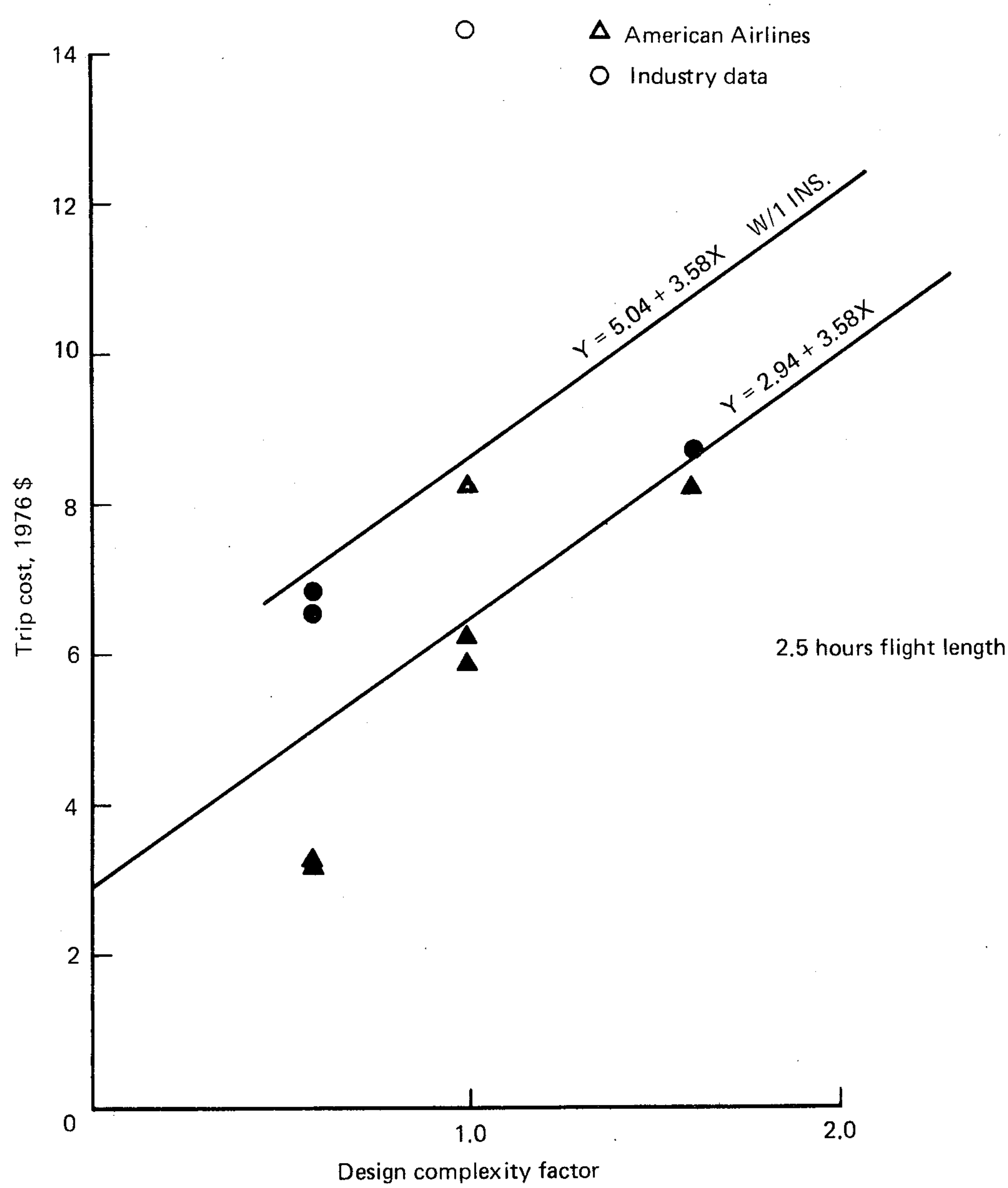

Figure 89.—ATA System 34—Navigation—Labor

Comments similar to System 34 Labor. The American Airlines and industry source 747 data points were excluded from this regression.

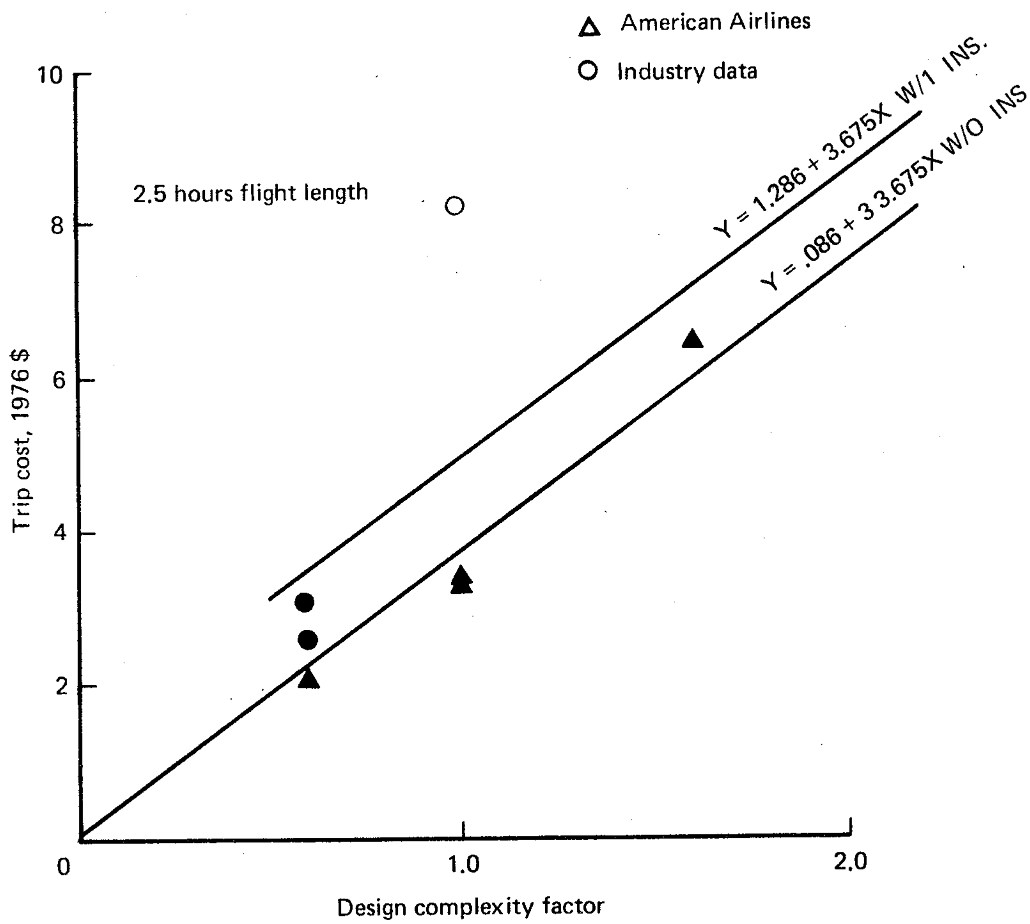

Figure 90.—ATA System 34—Navigation—Material

All data points were used in the regression.

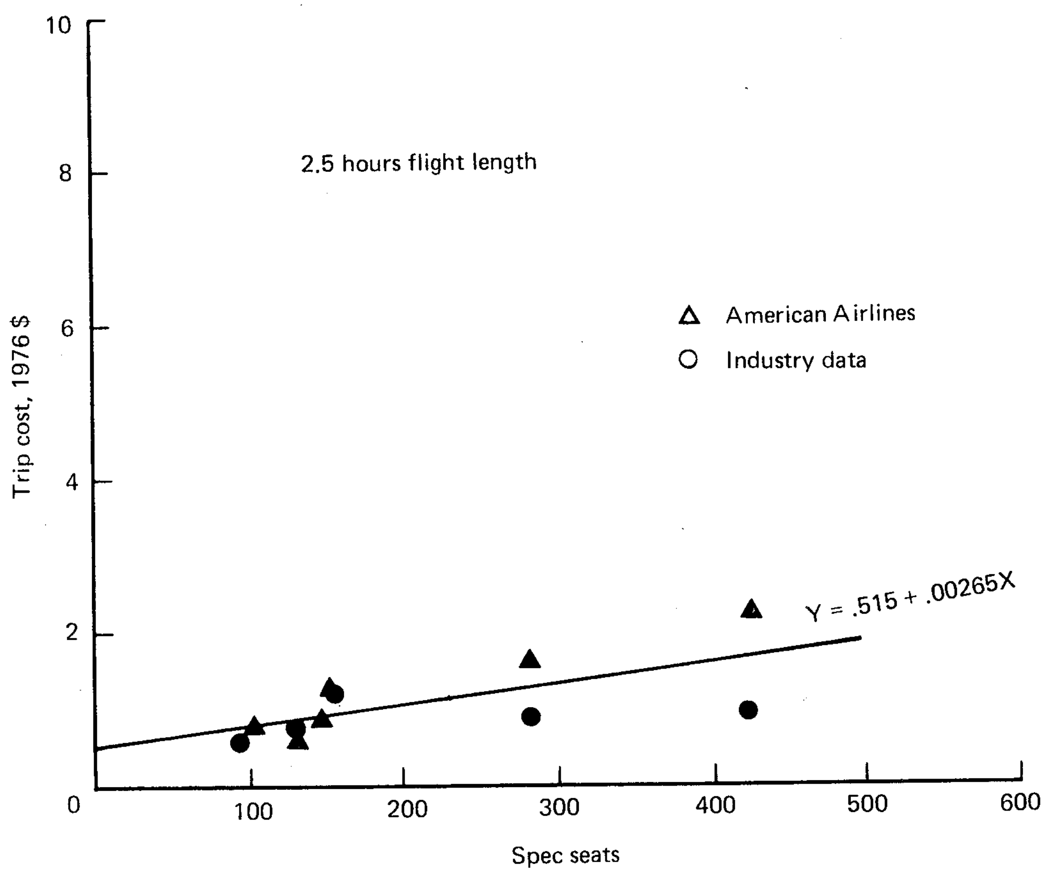

Figure 91.—ATA System 35—Oxygen—Labor

All data points were used in the regression of the lower curve except the DC-10 points. The DC-10 uses a different and unique system, i.e., a system of separate oxygen generators located in the seat backs. The conventional system consists of centrally located oxygen tanks and tubing for distribution to the passenger and flight deck crew locations. The upper curve was based solely on an average of two DC-10 data points which reflect a higher material cost.

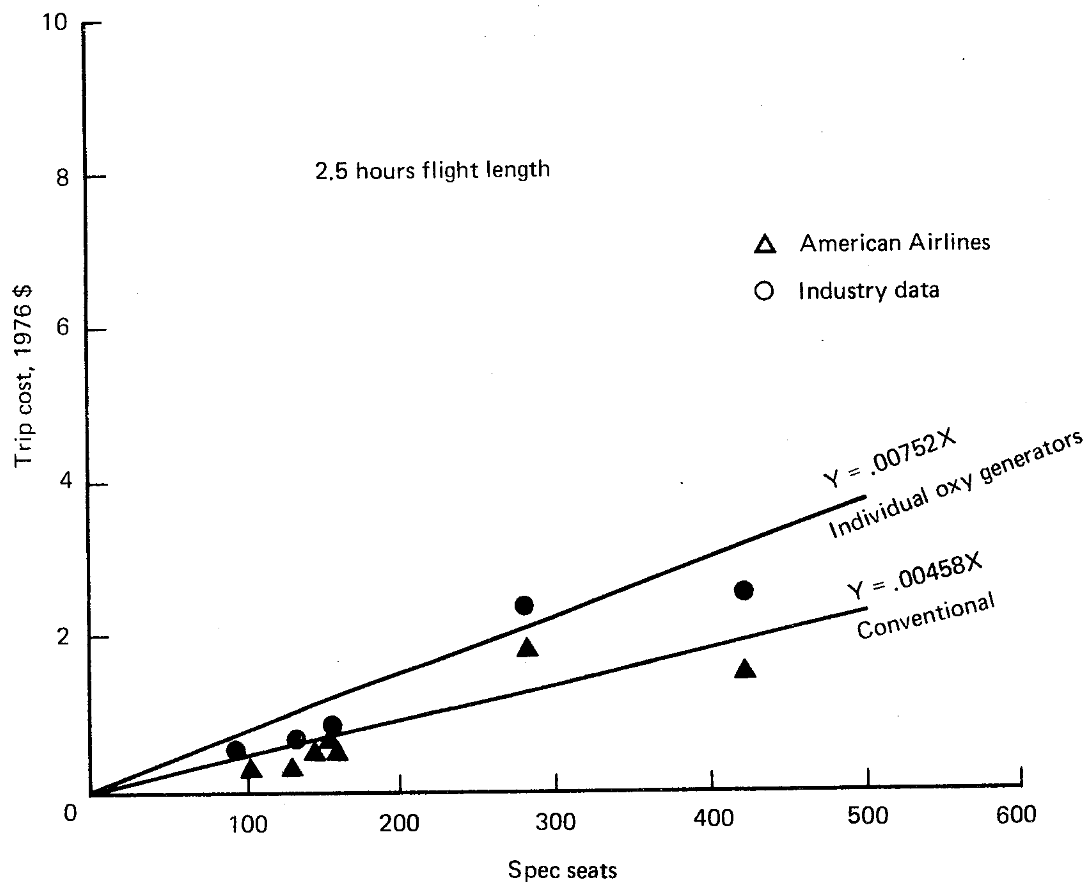

Figure 92.—ATA System 35—Oxygen—Material

All data points were used in the regression except the American Airlines DC-10 point which was unusually high. Since the pneumatic system is sized to comply with engine starting and air conditioning requirements, parameters reflecting engine and pneumatic systems were tried individually and combined. The combined total air conditioning pack capacity in kgs air flow per minute and engine thrust in newtons produced the best correlation.

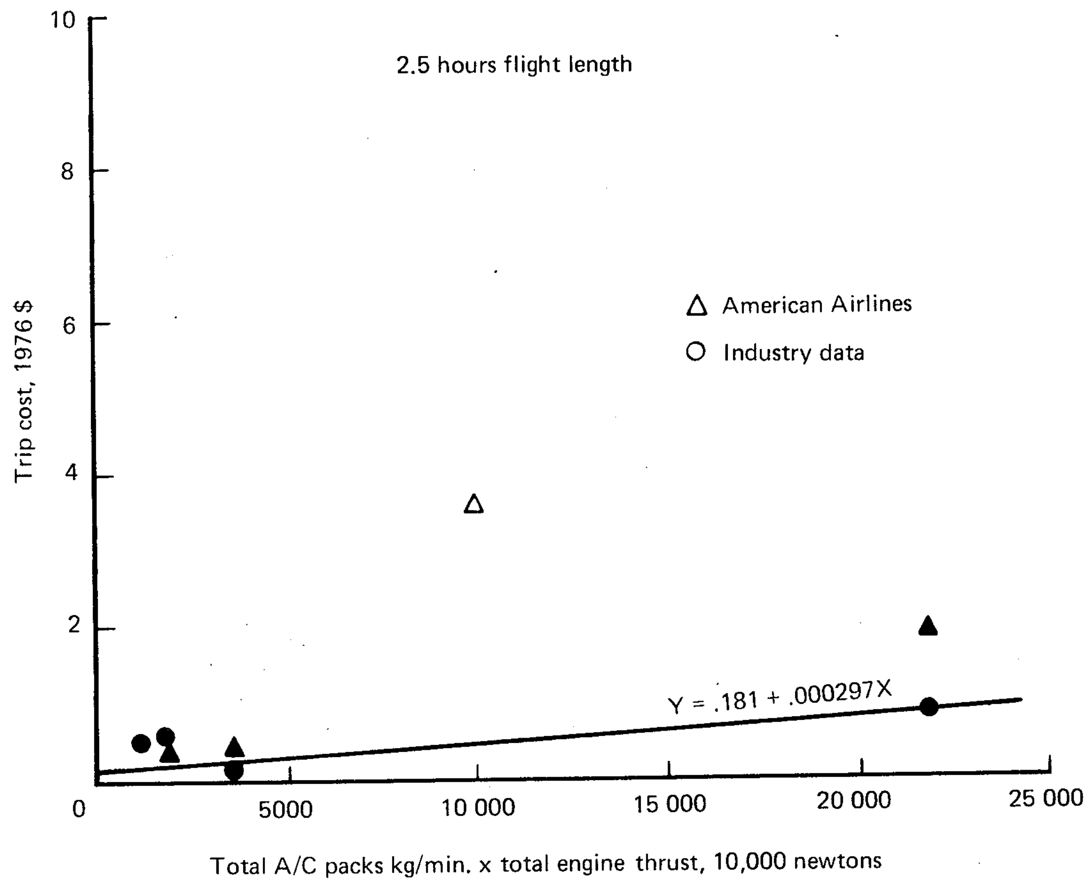

Figure 93.—ATA System 36—Pneumatics—Labor

Comments similar to System 36 Labor, except the AAL DC-10 point appeared satisfactory and was used.

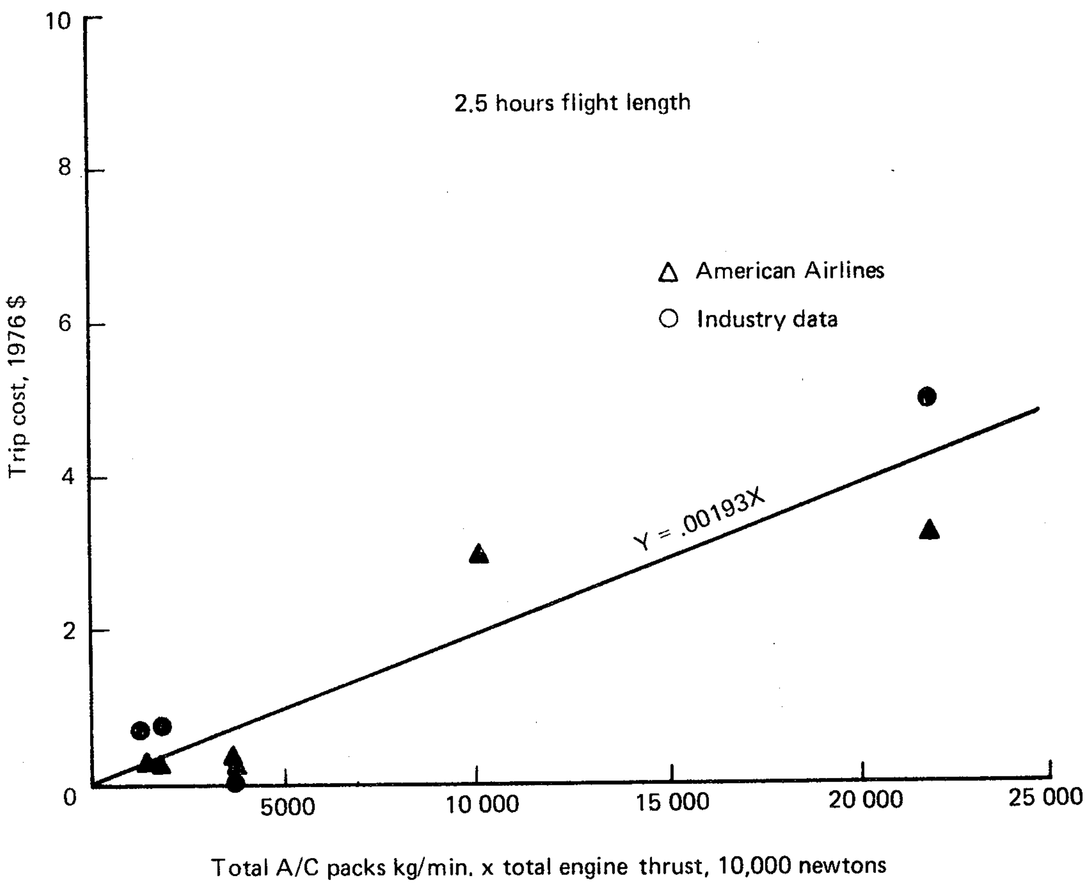

Figure 94.—ATA System 36—Pneumatics—Material

All data points were used for the regression. The size of the water and waste system is influenced by the same factors which effect the complexity of the equipment and furnishings system (System 25). As a result, the complexity factor used with System 25 was also used for this system in conjunction with the number of spec seats.

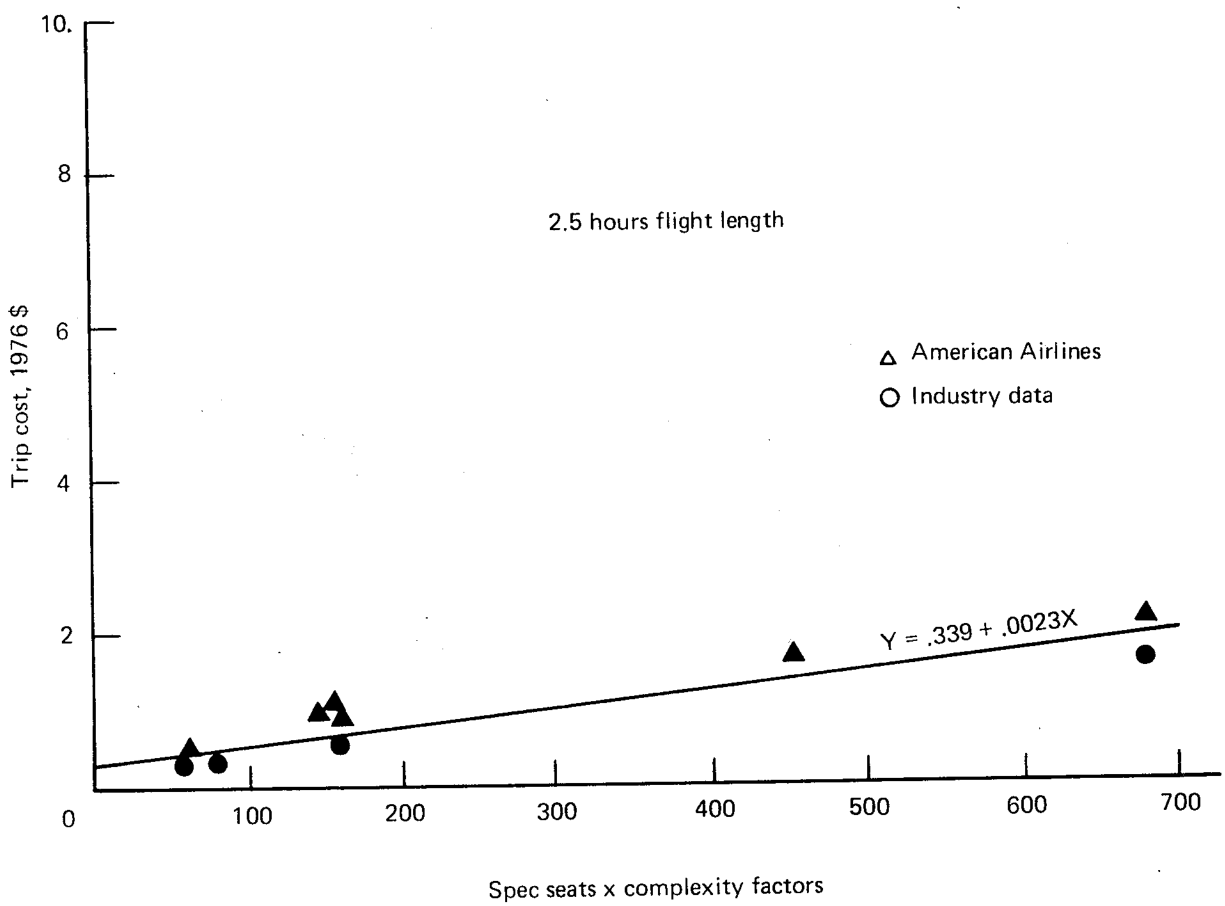

Figure 95.—ATA System 38—Water/Waste—Labor

Comments similar to System 38 Labor.

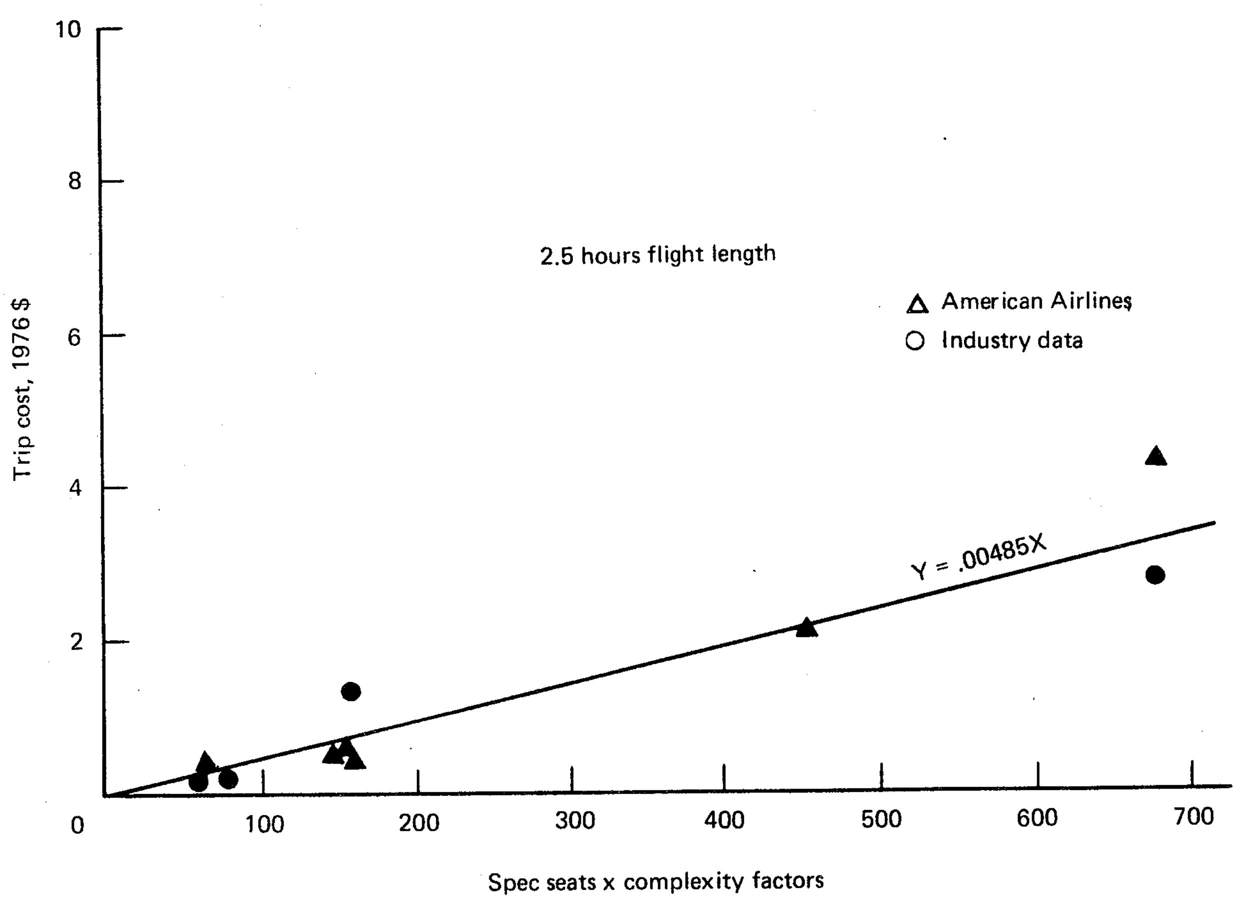

Figure 96.—ATA System 38—Water/Waste—Material

ATA System 49–Airborne Auxiliary Power Unit–Labor.–The airborne auxiliary power units (APU) are installed on the aircraft for the purpose of generating a combination of electric, hydraulic, and/or pneumatic power. When certificated they can be used in flight for emergency power needs but are generally used for electrical power and cabin air conditioning requirements when the aircraft is on the ground and the main engines are shut down. The APU operation is cyclic in nature as it is used between flights. However, there can be considerable periods of APU usage particularly at night during aircraft servicing and maintenance activities. In addition and depending on climatic conditions, it is not uncommon for the APU to be operated for extended periods to preclude the airplane interior from becoming either too hot or cold.

The American Airlines data were reduced to a cost per APU operating hour rather than a cost per flight in order that comparisons could be made with other source data. Cost per APU hour was easily obtained from the average cost per trip, knowing the trip time and the ratio of APU operating time to airplane operating time. Since the primary cost of the APU system is a single component it was felt that the vendor and industry source data provided a much more representative data sample than the American data. The industry source data is a compilation of airline and vendor data over several years through 1976. The vendor data is for the current year of 1977 and is not included in the industry source data.

Data correlation was attempted using equivalent shaft horsepower as a sizing function and then using airflow requirements but it was concluded that it was more rational to use a weighted average term containing both power takeoff shaft horsepower and airflow. Power takeoff horsepower reflects the standard usage of the APU while the airflow parameter reflects a design criteria for short term usage in starting the engines when considerable airflow is required, especially for the big high-bypass ratio engines.

The basic equation relates to a single spool, constant speed, simple design with fuel metering maintaining the APU exhaust gas temperatures within limits. The developed 1.8 factor relates to the more complex twin spool design with the N_2 rotor operating at constant RPM for electrical power generation and controlled by a fuel control. The N_1 rotor is a variable speed compressor to supply varying pneumatic requirements with control through complex variable turbine nozzle guide vanes. The advantage of the more complex APU is a reduction in specific fuel consumption during APU operation. There will continue to be APU systems with varying degrees of complexity where it will be necessary to establish a complexity factor between 1 and 1.8 to adequately reflect their costs.

To provide the capability of calculating APU system trip costs, a representative function of APU usage per airplane flight hour as a function of airplane flight length was defined from a wide range of 1975-76 time period airline experience. This is shown in figure 99. It should be noted that as fuel costs are becoming a more critical problem, the airlines are initiating programs to decrease the amount of APU usage.

As seen in figure 99, American Airlines APU usage has been considerably higher than the industry average.

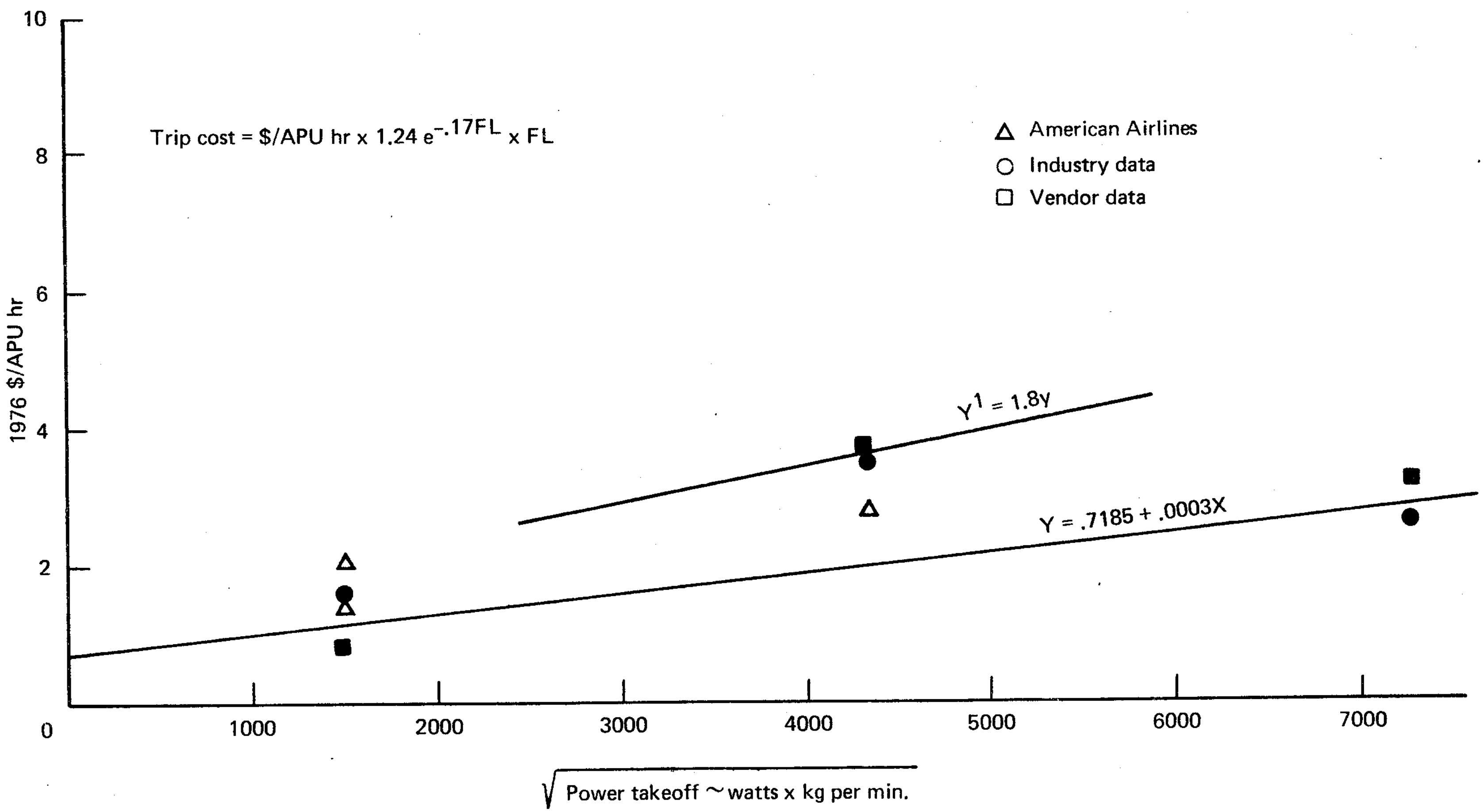

Figure 97.—ATA System 49—Airborne Auxiliary Power Unit—Labor

Comments similar to System 49 Labor.

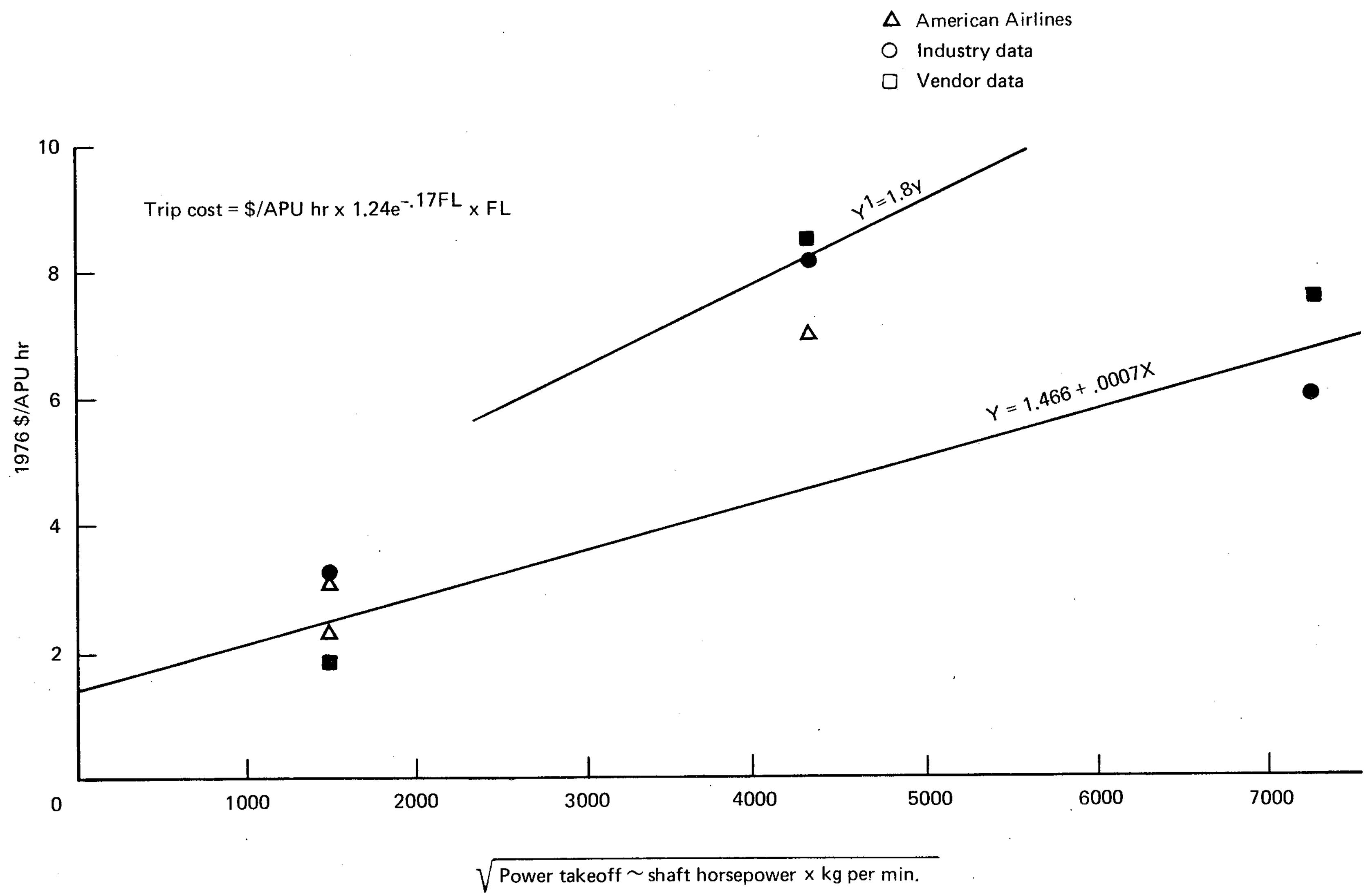

Figure 98.—ATA System 49—Airborne Auxiliary Power Unit—Material

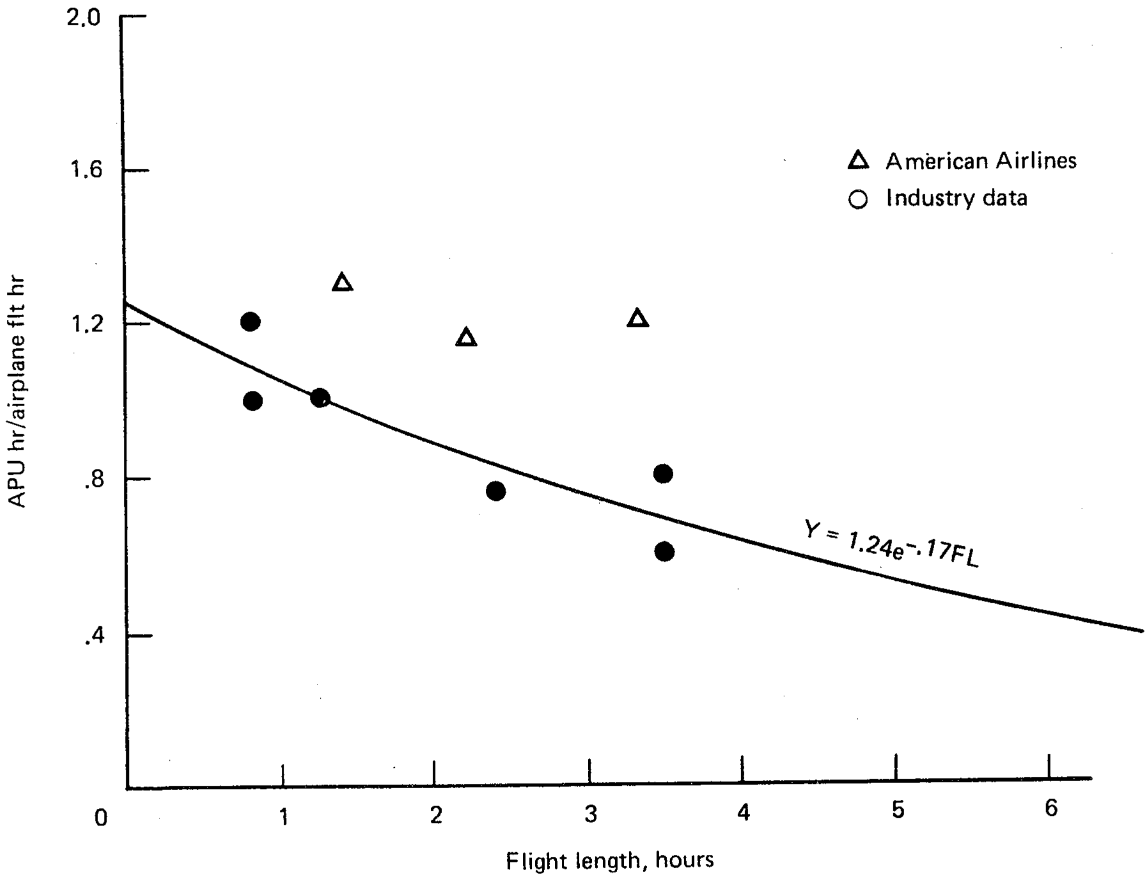

Figure 99.—ATA System 49—Airborne Auxiliary Power Unit—Usage Rate

System 50 represents miscellaneous structures labor costs. Miscellaneous structures materials costs are not reported. Since much of the ATA structures systems uses airplane size as a parameter such as seats or airframe weight, the parameter of airframe weight was selected for this system. Industry source data was not available for this system since these costs are normally pre-allocated into the various ATA structures systems. All AAL data points were used in the regression.

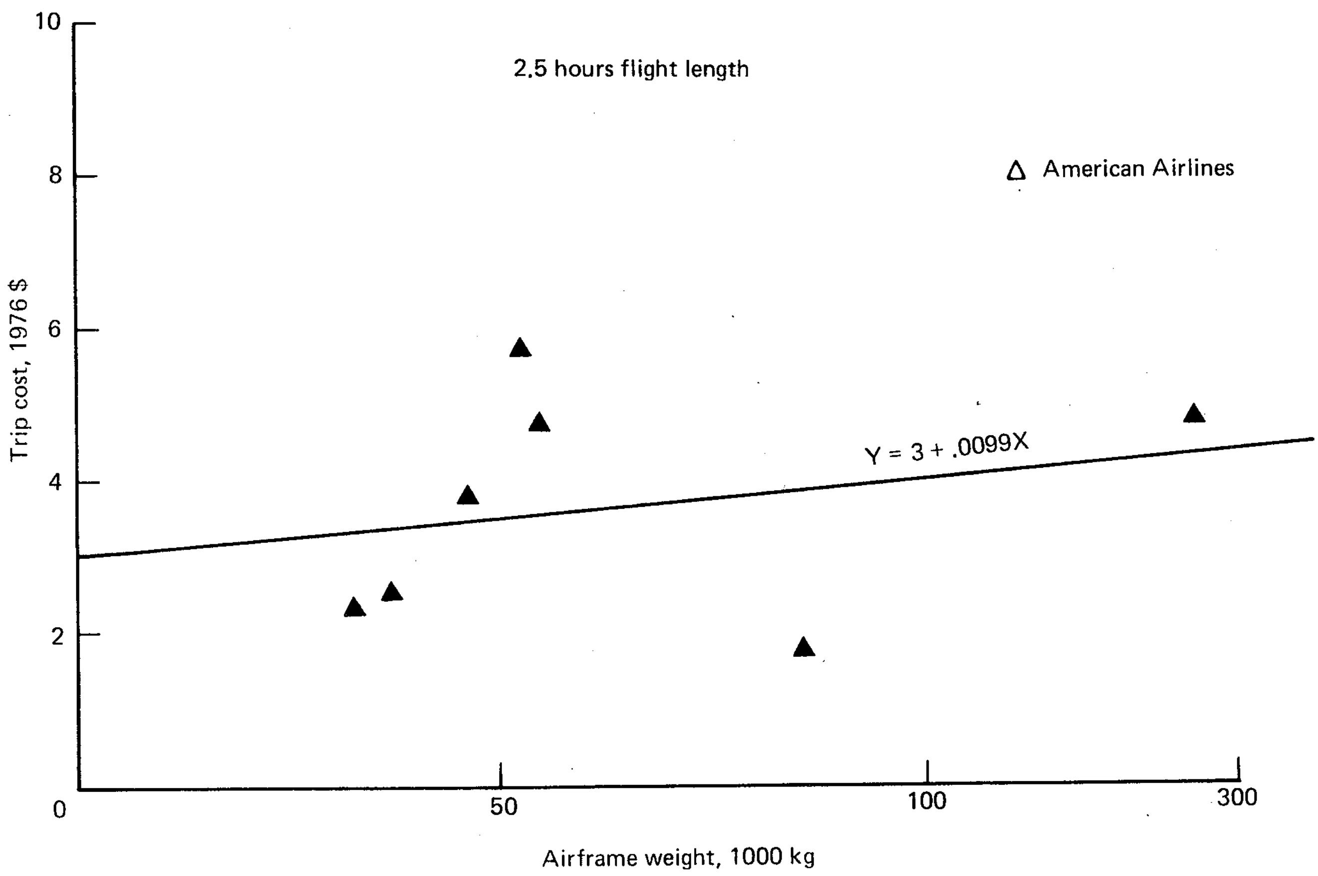

Figure 100.—ATA System 50—Miscellaneous Structure—Labor

All data points except the industry source 747 and 707 points were used. The 747 point was unusually low and the 707 point unusually high. The door costs include the total interior and exterior doors which are sufficiently related to total passengers or spec seats to use seats as the parameter for this system. (Note: in AAL aircraft interior doors expenses are charged to ATA System 25–Equipment and Furnishings.)

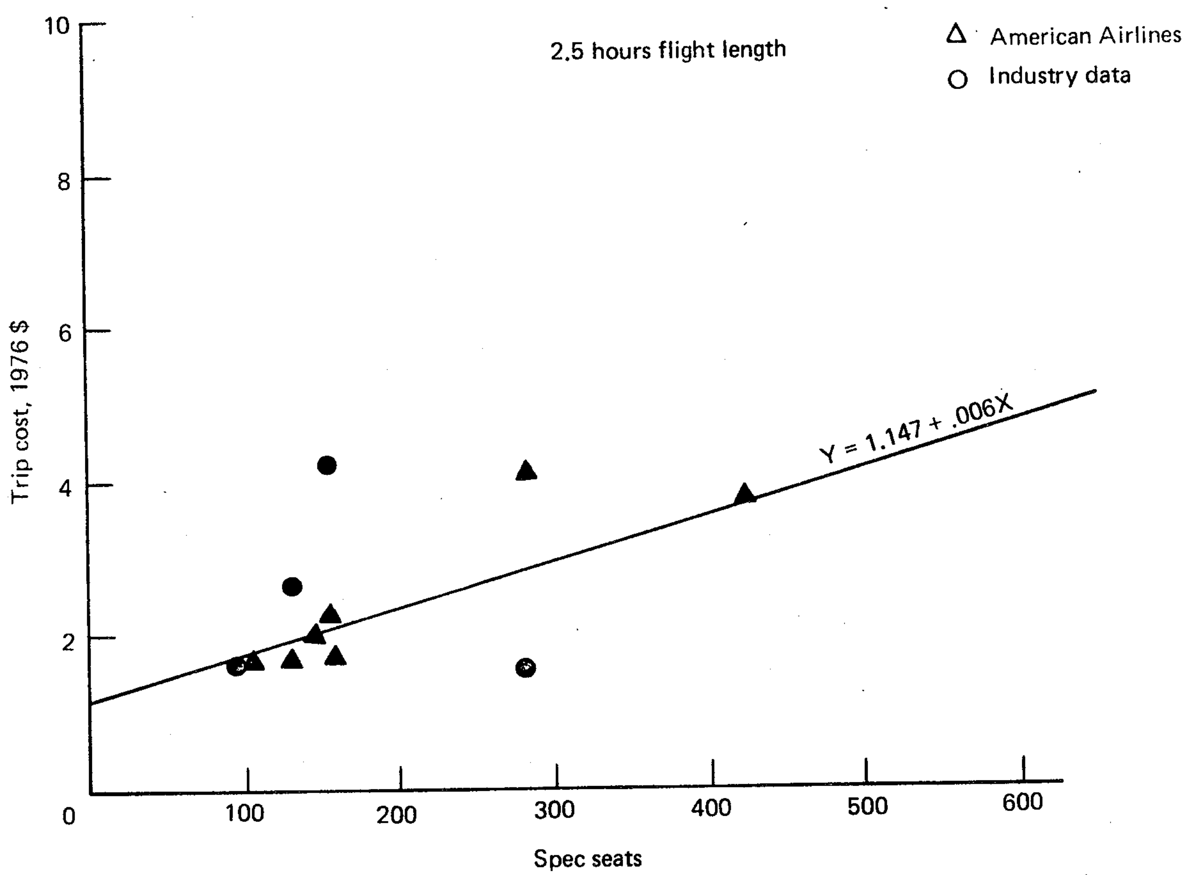

Figure 101.—ATA System 52—Doors—Labor

Comments similar to System 52 Labor apply, but in this case, the industry source 747 point was satisfactory and was incorporated.

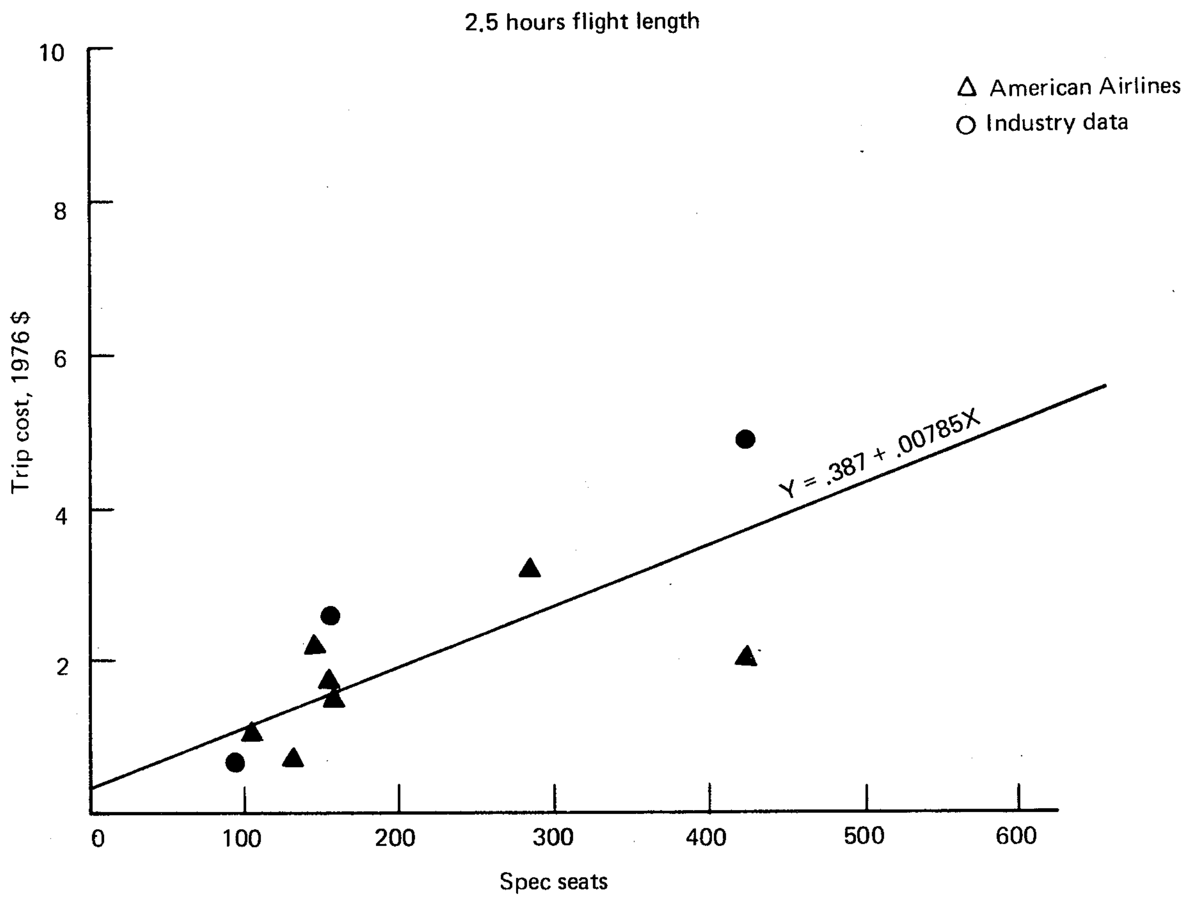

Figure 102.—ATA System 52—Doors—Material

All American Airlines data points were used in the regression along with the 727 and 737 industry source data points. The other industry source data points appeared to include a sufficient amount of miscellaneous systems labor to distort the overall regression and were not used.

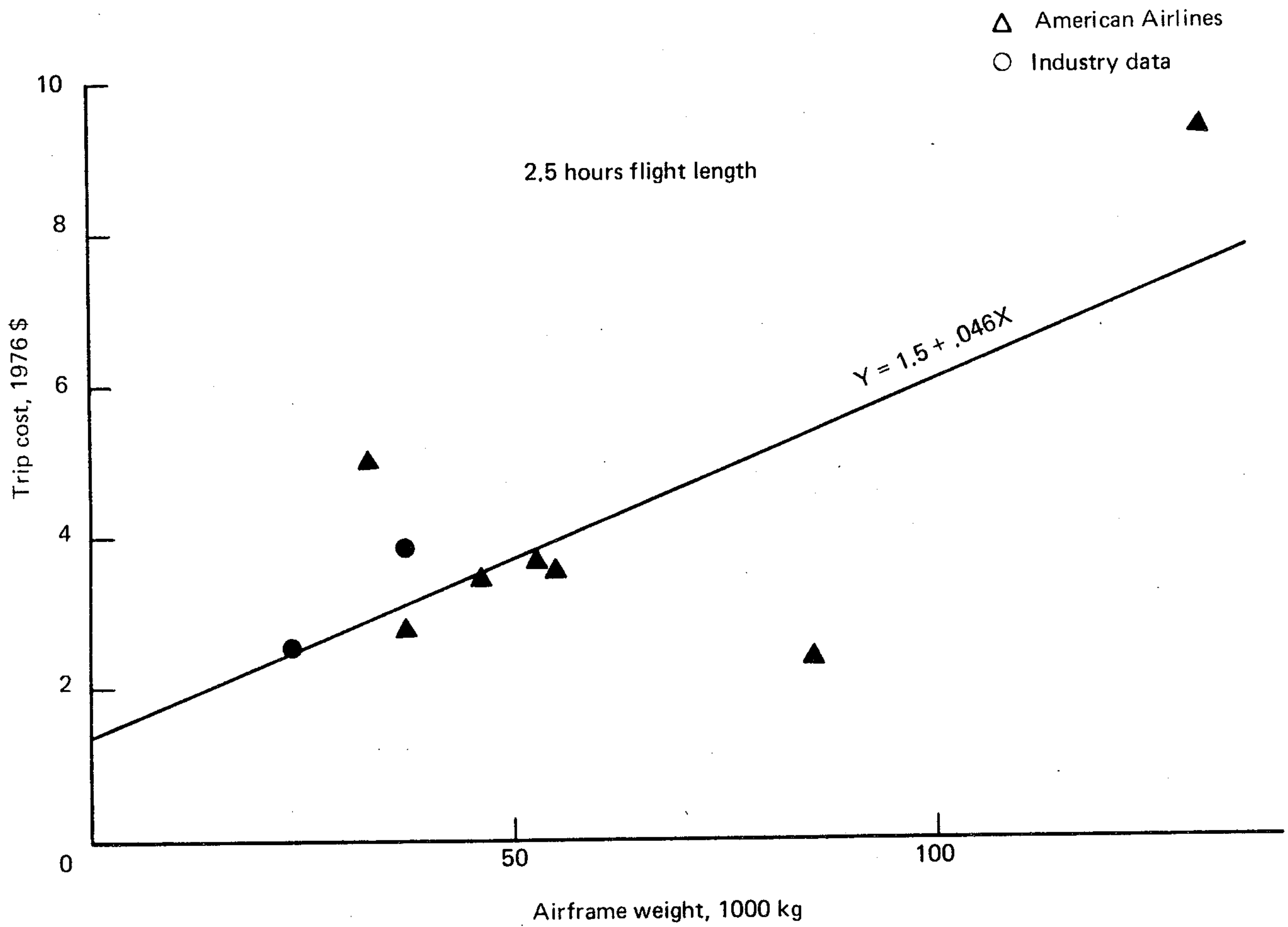

Figure 103.—ATA System 53—Fuselage—Labor

For the material all American Airlines and industry source data points were used. The data points appear to be independent of any parameter.

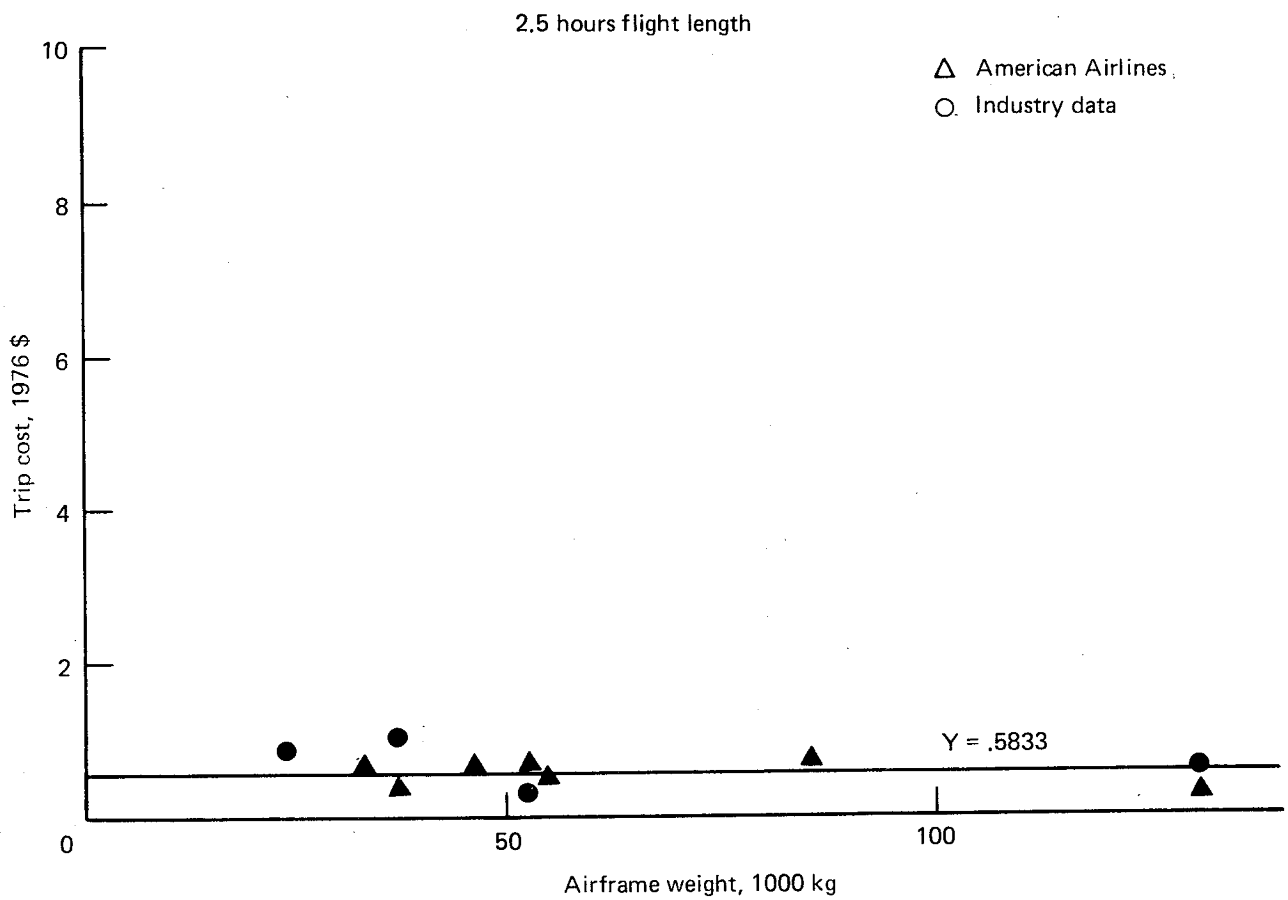

Figure 104.—ATA System 53—Fuselage—Material

All American Airlines and industry source data points were used in the regression. The industry source data for labor contains pre-allocated portions of the miscellaneous systems costs and are higher than the equivalent AAL data. The number of podded nacelles external to the fuselage appeared to be a logical choice for the nacelle pylon system correlating parameter, and provided a satisfactory regression.

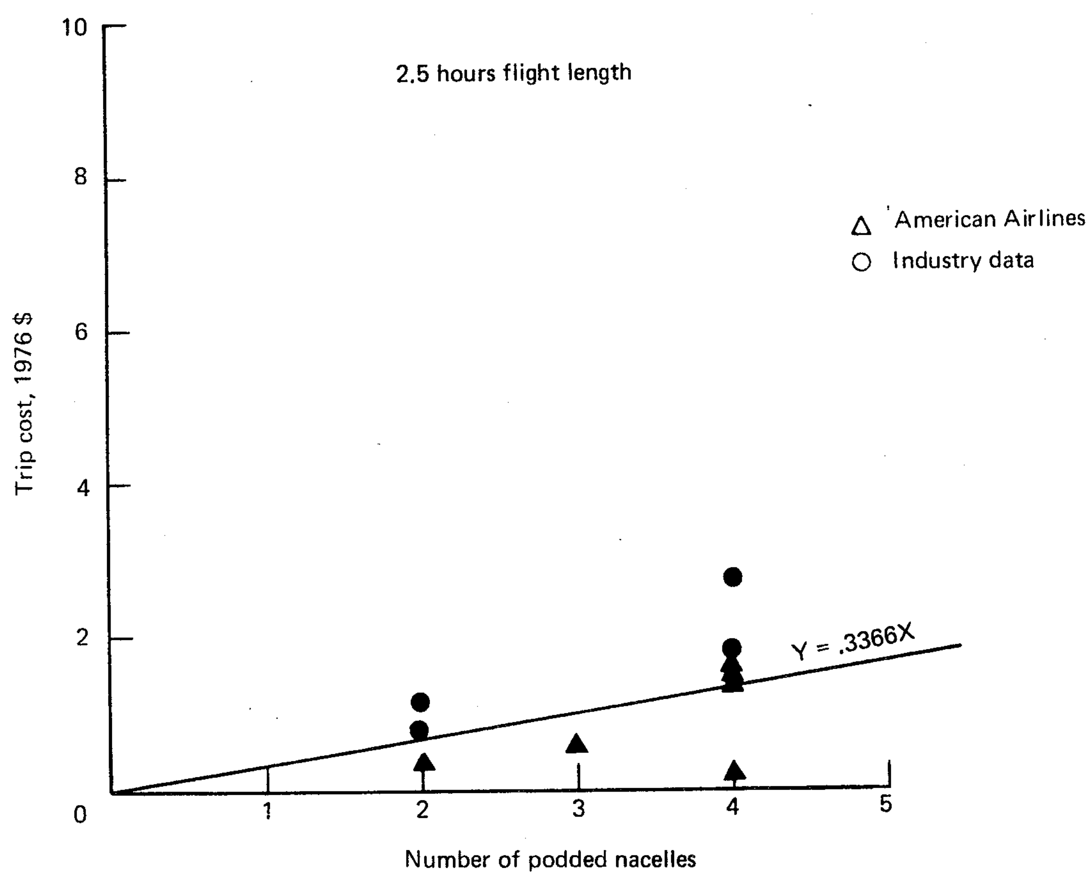

Figure 105.—ATA System 54—Nacelles/Pylons—Labor

Similar comments to ATA System 54 Labor apply; however, in this case the industry source material data points are closer to the American Airlines points.

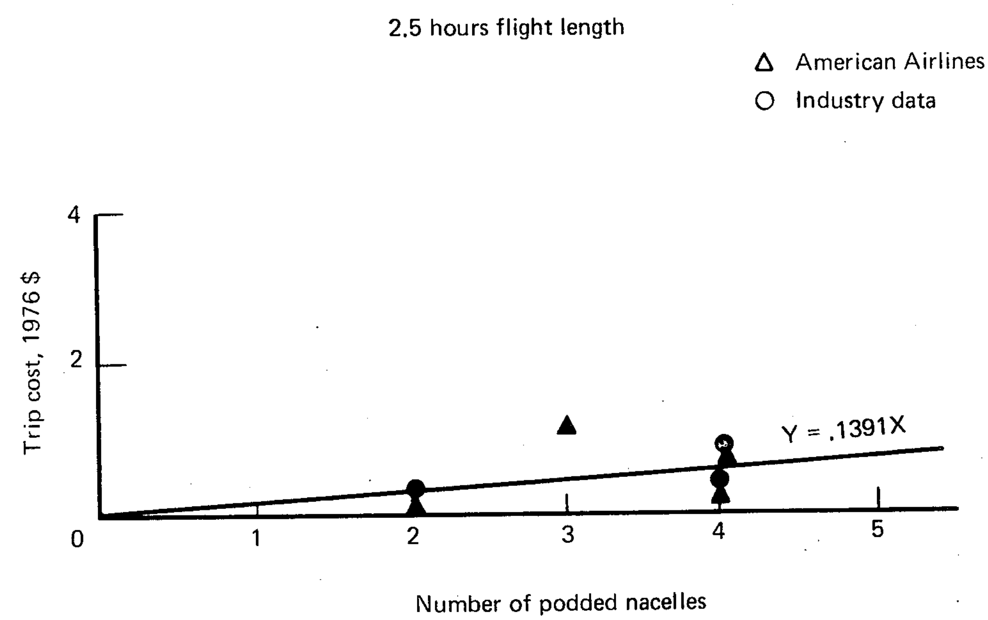

Figure 106.—ATA System 54—Nacelles/Pylons—Material

All American Airlines data points were used in the regression; however, the industry source data for the labor appeared to include sufficient amounts of miscellaneous systems costs to warrant their exclusion. The constant nature of the data suggests no parameter dependence.

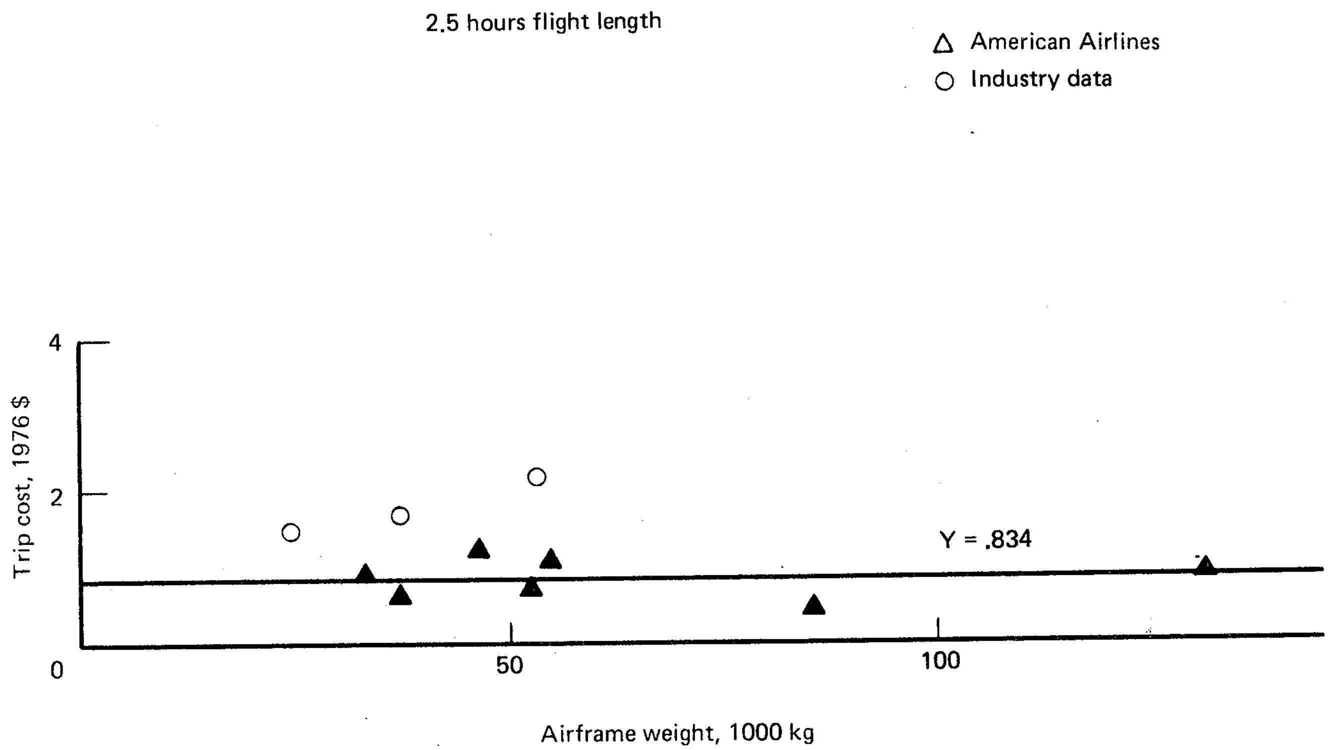

Figure 107.—ATA System 55—Stabilizers— Labor

All American Airlines and industry data points were used in the regression except for the industry source 747 data point which was unusually high, possibly due to inadequate sample size. As illustrated, the data appears independent of any parameter.

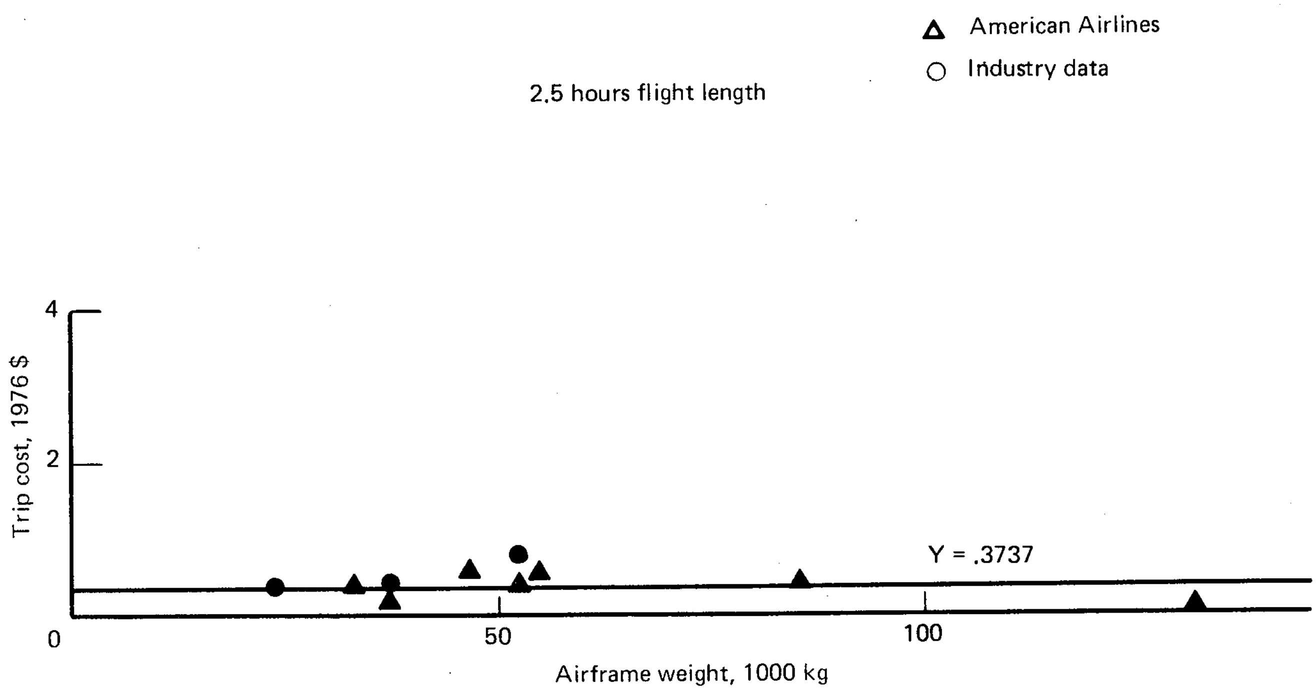

Figure 108.—ATA System 55—Stabilizers—Material

All American Airlines and industry source data points were used in the regression except the American Airlines 747 point. The American Airlines 747 point is shown for reference. The window costs are primarily in the windshield, and the curved windshields on the 747 have higher material costs than the flat windshields. However, the labor costs should not reflect the same cost relationship of curved versus flat windshields as in the case of material expenditures. The industry source 747 data point was considered more representative of the fleet than the American Airlines data point.

The labor plot uses spec seats as a parameter; however, the resulting curve is nearly flat, implying little dependence on airplane size.

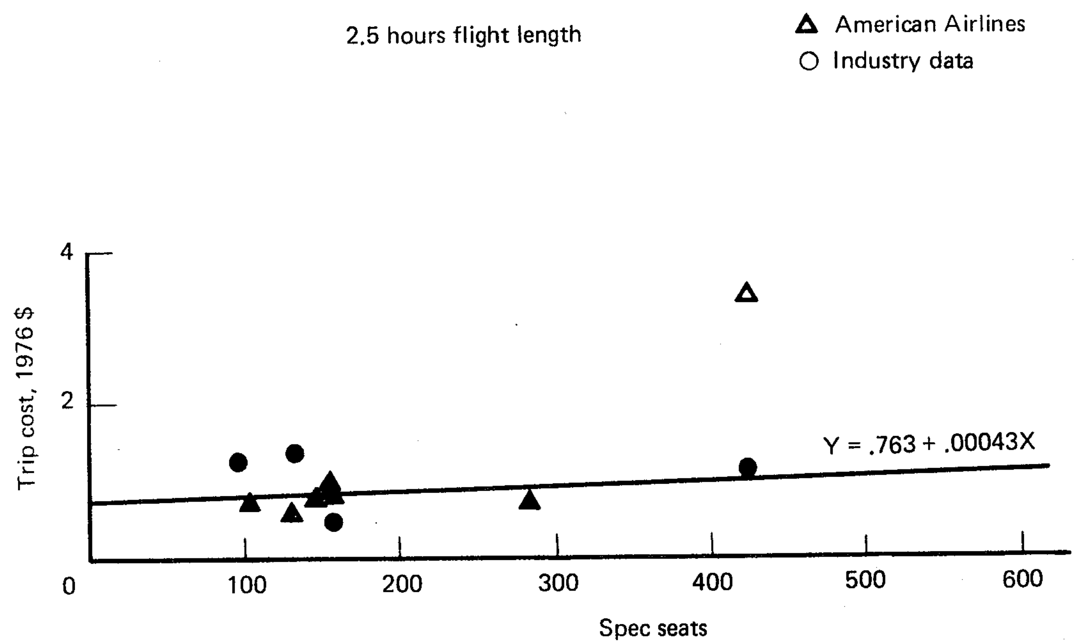

Figure 109.—ATA System 56—Windows—Labor

All American Airlines and industry source data points were used in the regression of the basic curve for flat windshields except for the points which reflect the unique curved windshield. The two 747 points (American Airlines and industry) were averaged and used to construct the upper curve for curved windshield material costs. Unlike the labor curves for this system, the material costs appear to have a definite association with airplane size. Other parameters tried included airframe weight. Spec seats were determined to be a more logical parameter choice since it relates to the number of passenger windows, which also contribured to the overall system costs.

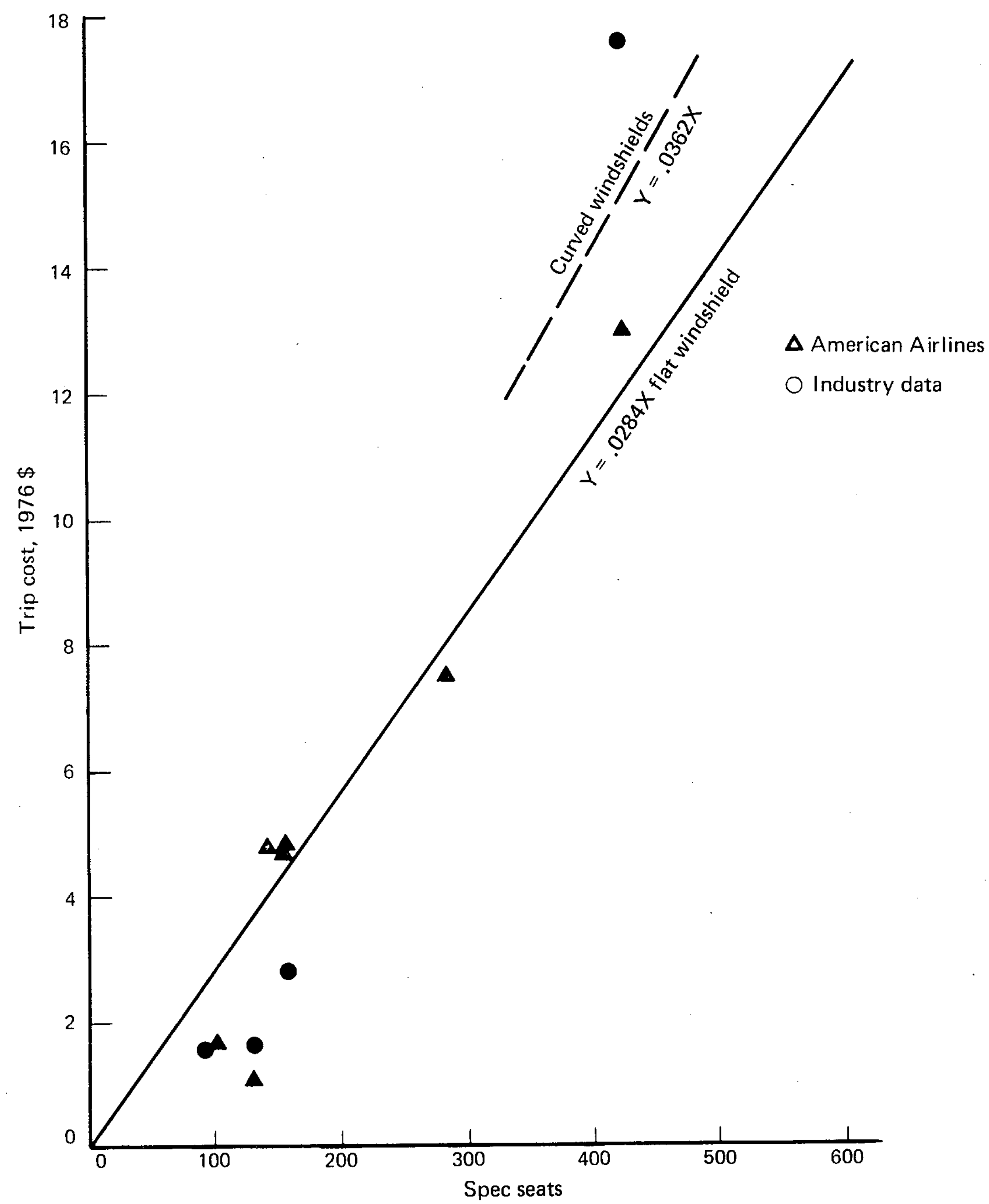

Figure 110.—ATA System 56—Windows—Material

All American Airlines data points and part of the industry source data points were used in the regression. The 707 and 747 industry source points were unusually high as a result of their including large amounts of labor costs from the miscellaneous systems. They were excluded. The remaining data points appear random in nature and do not correlate well with any parameter tried. The material expense and the combined labor plus material expenditures do correlate with wing size. Therefore, wing area was considered to be a reasonable parameter choice, and a constant appropriate for the available labor data.

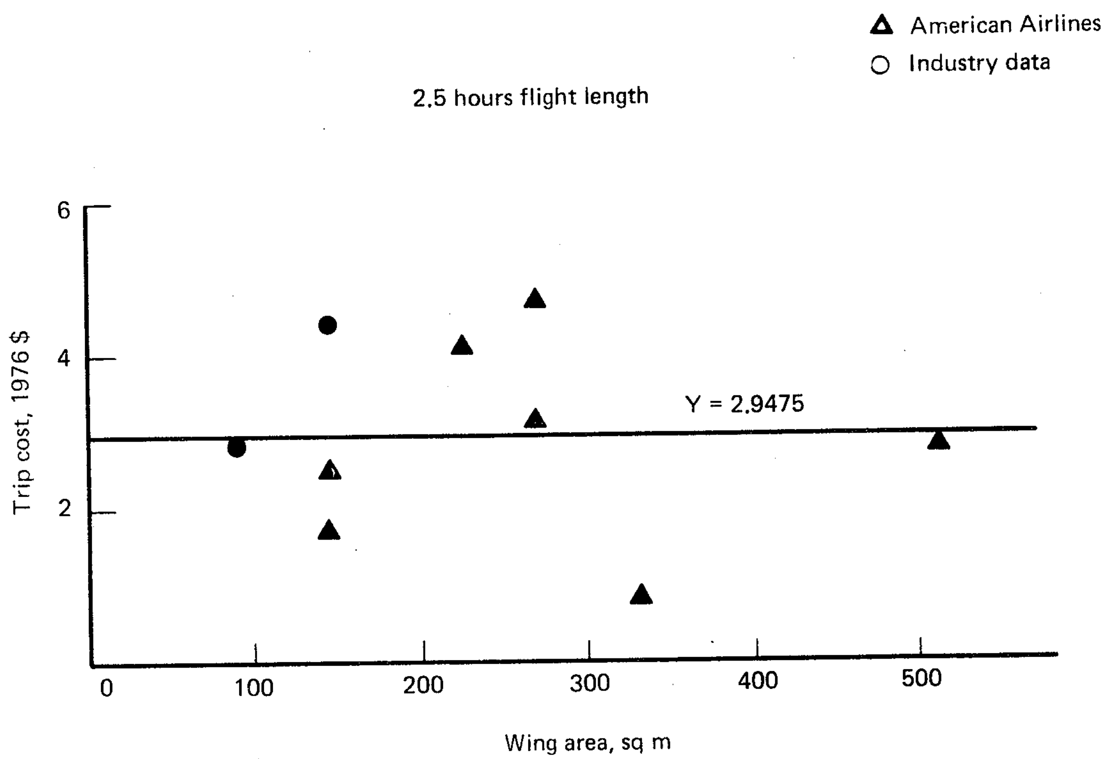

Figure 111.—ATA System 57—Wings—Labor

All American Airlines and industry source data points were used in the regression except the 747 industry point. This point was unusually high compared with the similar American Airlines point, probably as a result of inadequate or incomplete data. For the remaining points the dependence on wing area is evident and the combined labor and material costs showed an even better correlation with wing area. Weight was also tried as a parameter.

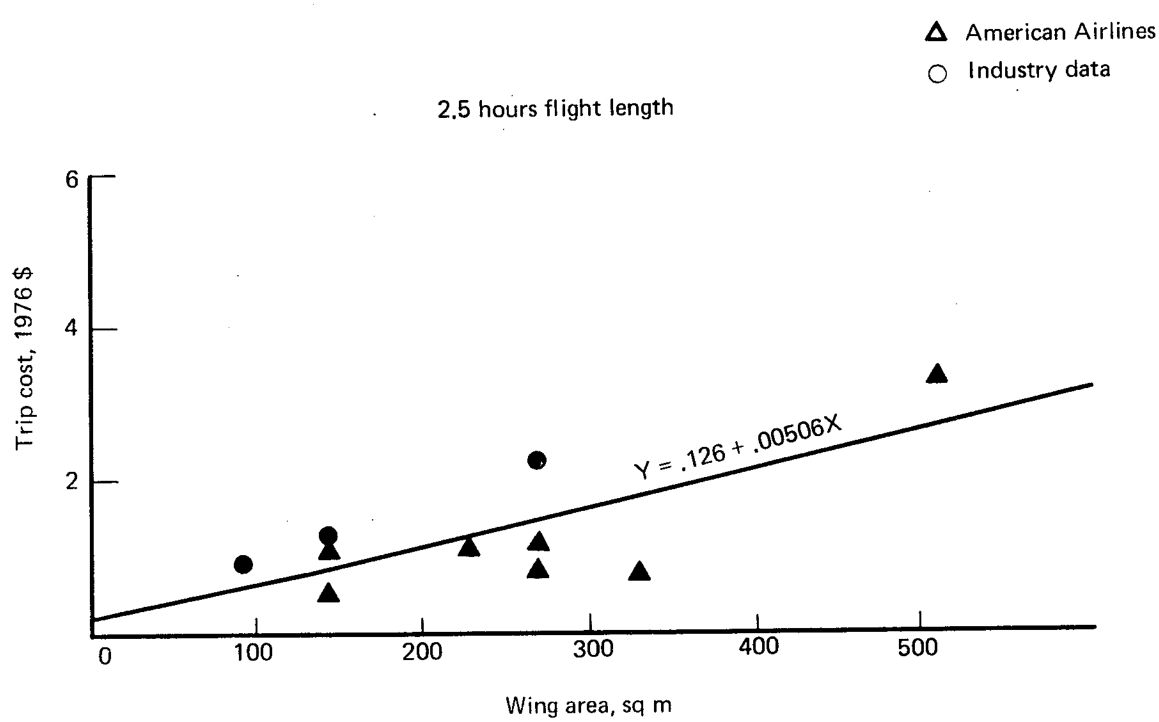

Figure 112.—ATA System 57—Wings—Material

4.4.5.10 Data Verification

Figure 113 illustrates how the parametric method correlates to actual reported costs as contained in the CAB form 41 reports for aircraft used as the data base. Note that the fleet 727-200 costs are lower than the parametric data due to dilution effects of 83 727-200's being added to the domestic fleet in the 1974 and 1975 time period. The costs defined by the parametric method for the 747 are slightly lower than the U.S. fleet average which is to be expected. All U.S. domestic 747's were delivered during the first two years of production with no additional improved aircraft being added to the fleet since 1972. Extensive improvements in the multiplex system, windshields, navigation unit, leading edge drive units, etc., since the time period have significantly reduced maintenance costs. These airline-experienced reduced costs are reflected in Boeing's worldwide industry data records.

Table 13 summarizes the airplane characteristics used to generate the curves on figure 113.

4.4.5.11 Technology Effects on Airframe Maintenance Costs

Introduction.—The commercial jet transports that will evolve during the 1990's will be designed for economical operation utilizing fossil fuels which may be three to four times higher in price than present day levels. Alternately, since fossil fuels may cease to exist as an economically viable energy source for commercial aircraft propulsion systems, other energy forms must be developed and adapted. The alternative energy sources include liquid hydrogen, liquid methane and possibly nuclear energy. In any event, the rising price of fossil fuels and eventual use of other fuel types will cause a tremendous impact on aircraft design technology, operations, and maintenance. Fuel economics will demand not only more efficient propulsion systems, but will also cause improvements and advancements specifically in aerodynamics, airframe structures, controls, fuel and other airframe systems.

Along with improvements in airframe technology will come new problems in maintenance. New materials and processes will cause new repair techniques to be developed, procurement of additional shop tooling to support repair and fabrication of composite materials, and a potential lack of component commonality between the new and then existing airplanes.

Materials Technology—Aircraft Structures.—The development of lighter and stronger airframe structures has always been an enforced discipline within the aircraft industry. As each generation of airplanes evolved, state-of-the-art technology provided new materials (essentially metals), with improved strength to weight ratios, improved corrosion resistance and hopefully, reduced operating costs. Although nonmetals are used extensively in present technology aircraft, their application has been limited almost exclusively to interior trim, galleys, toilets and windows, and in most cases contributing little or nothing to airframe structural integrity. Government sponsored research within the missile industry has resulted in the development of composite materials which utilize filaments of boron, graphite, glass, and resin binders which provide a structural medium with strength to weight ratios that are technically competitive with existing aircraft metals, but due to high production costs are not compatible with aircraft economics.

To enhance the development of composites, Department of Defense funding endorsed the use of composites on military aircraft, initially on substructures, control surfaces, and ultimately wing panels. Research and Development funding provided by NASA to commercial aircraft manufacturers has expedited the application of composite structures in the form of ailerons, rudder sections, and spoilers,

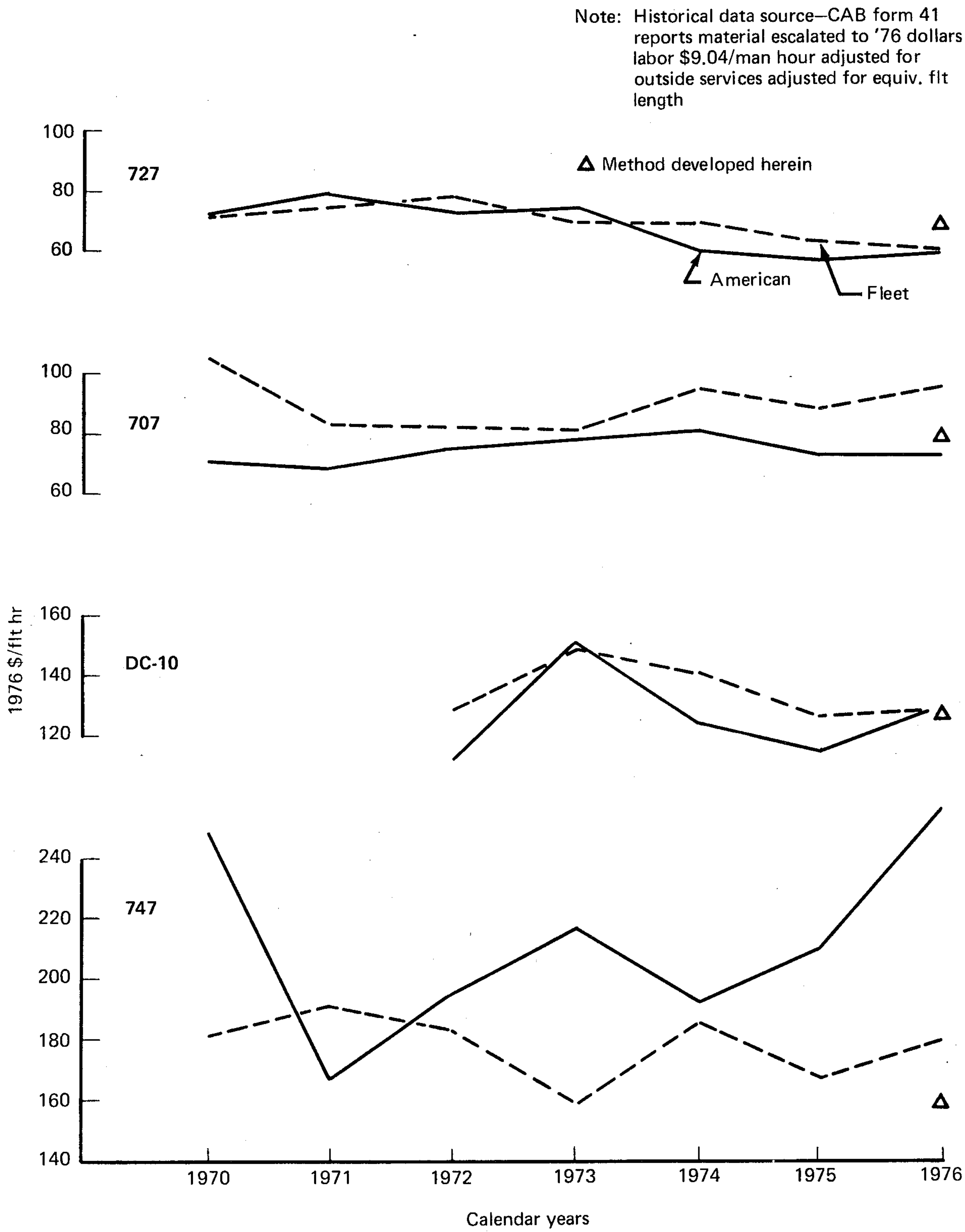

Figure 113.—Airframe Maintenance—1976 Dollars Per Flight Hour

Table 13.—Summary of Airplane Characteristics—Data Verification

	727-200	707-300B	DC-10	747	TAC/ energy	CWB-E
1. Flight length in hours	1.39	2.27	2.24	3.33	2.27	2.3
2. Airframe weight in kg	37 000	52 400	85 300	131 400	58 200	72 400
3. Air conditioning total kg air flow per minute	95.3	113.4	190.5	281.2	149.7	149.7
4. Number operating autopilot channels	1	1	2	2	2	2
5. Number design seats	131	157	282	423	196	196
6. MUX installed	NO	NO	YES	YES	YES	YES
7. Number inflight operated elec. generators	3	4	3	4	4	3
8. KVA rating of full time generators	120	160	270	240	300	270
9. Design complexity factor (.6, 1., 1.6)	.6	1.0	1.6	1.6	1.6	1.6
10. Engine thrust in newtons per engine	62 300	80 100	177 900	193 500	67 600	144 100
11. Number engines	3	4	3	4	4	3
12. Total fuel capacity in kg	23 400	72 500	66 100	144 800	44 900	54 400 EST
13. Total LPM of full time hydraulic pumps	145	174	863	575	560	863
14. Maximum gross weight in kg	78 000	151 100	186 000	322 100	115 300	147 200
15. Number of INS installed	0	0	0	3	0	0
16. Individual oxygen generators used	NO	NO	YES	NO	YES	YES
17. APU spec. air flow in kg per minute	49.0	0	174.6	249.5	174.6	140.6 EST
18. APU spec. shaft watts	44 740	0	105 890	211 780	126 770 EST	85 760 EST
19. APU complexity factor (1.0 to 1.8)	1	0	1.8	1	1.8	1.8
20. APU operating hours per APL flight hour		(DETERMINED BY APU USAGE EQUATION)				
21. Number podded external nacelles	2	4	3	4	4	3
22. Conventional windshield used	YES	YES	YES	CURVED	YES	YES
23. Wing area in sq. M.	144.9	268.7	329.8	511.0	198.6	272.8
24. Type engine fire detection (single/dual)	SINGLE	SINGLE	DUAL	DUAL	DUAL	DUAL
25. Labor rate in dollars per hour	9.04	9.04	9.04	9.04	9.50	9.50
26. Material escalation factor from 1976 $	1	1	1	1	1	1

which are being service tested in airline operations. Although experience to date indicates that composites are providing satisfactory service in an operational environment, some problems have been encountered; moisture absorption in certain composites (graphite-epoxy), galvanic action between metal and composite bond joints, excessive wear and/or failures in quick release fastener holes and some edge delamination due to the combined rigors of flight operations and ground handling.

Many difficulties have been experienced in present state-of-the-art fabrication techniques. Among the difficulties encountered are the incompatibility of existing aircraft fabrication techniques (Numerical Control Machines) with composite tape and cloth lay up requirements, the high labor requirements, high rejection rates, requirement for large auto-claves, less than expected weight savings, and high material costs (see fig. 114).

Needless to say, composites technology is in an embryonic stage, and many growing pains are expected. Manufacturering techniques will be developed, numerically controlled fabrication techniques will be perfected, shop personnel will be reeducated, and component/assembly rejections will decrease. Also, material costs will decrease as demand increases. On the negative side, large capital expenditures will be imposed on the airframe manufacturers in the form of new tooling requirements.

Advanced Metals.—Although composites offer the most promising capability in aircraft structures, their initial usage will probably be limited to less than 15% of the airframe weight. Advanced metals, aluminum, titanium and steel will still maintain dominance in the technology of the 1990's. As experience is gained, composites could eventually displace metals even on certain primary structures (see fig. 115).

Aircraft Systems.—Probably the most significant technology gains within the aircraft systems will be in aircraft controls, auto-flight, communications and instruments.

With the advent of composites technology, aircraft controls will benefit both in weight savings and hopefully reduced maintenance costs. Actuating systems will change from the present hydraulic driven to electrically driven actuators possessing ultrafast response capability. Essentially, this will be a combination of the fly-by-wire concept and full time active controls. Benefits of this technical combination will allow for reduced sizing of some of the control surfaces, more latitude in C.G. range, and relative wing location in the basic airframe design. The fly-by-wire/active controls system will demand selection of components with very high reliability, multiple redundancy, and fail safe capability. To facilitate the operational requirements of a fly-by-wire/active control system, new hardware technology must provide the rate sensors, fast response electrical actuators and computer hardware necessary to accommodate safe and reliable operation. Control redundancy can be provided by parallel multiplexing, where each multiplex monitor and control cable can provide at least 10 channel sampling capability and handle 20 000 digital sample bits/second. The use of multiplexing in lieu of steel hydraulic lines will also reduce airframe weight and maintenance costs.

Laminar flow control systems have been in development for many years and provide an effective means of reducing airplane drag, fuel burn, and can enhance engine derating. With all the apparent merits of this system, it has not been incorporated in any production airplane to date. Since this system required bulky compressors and ducting, their installation was usually in large pods attached externally to the wing and somewhat offset the purpose of the system in reducing drag. Since the supercritical wing offers a much thicker cross section than previous wing designs, it provides an ideal

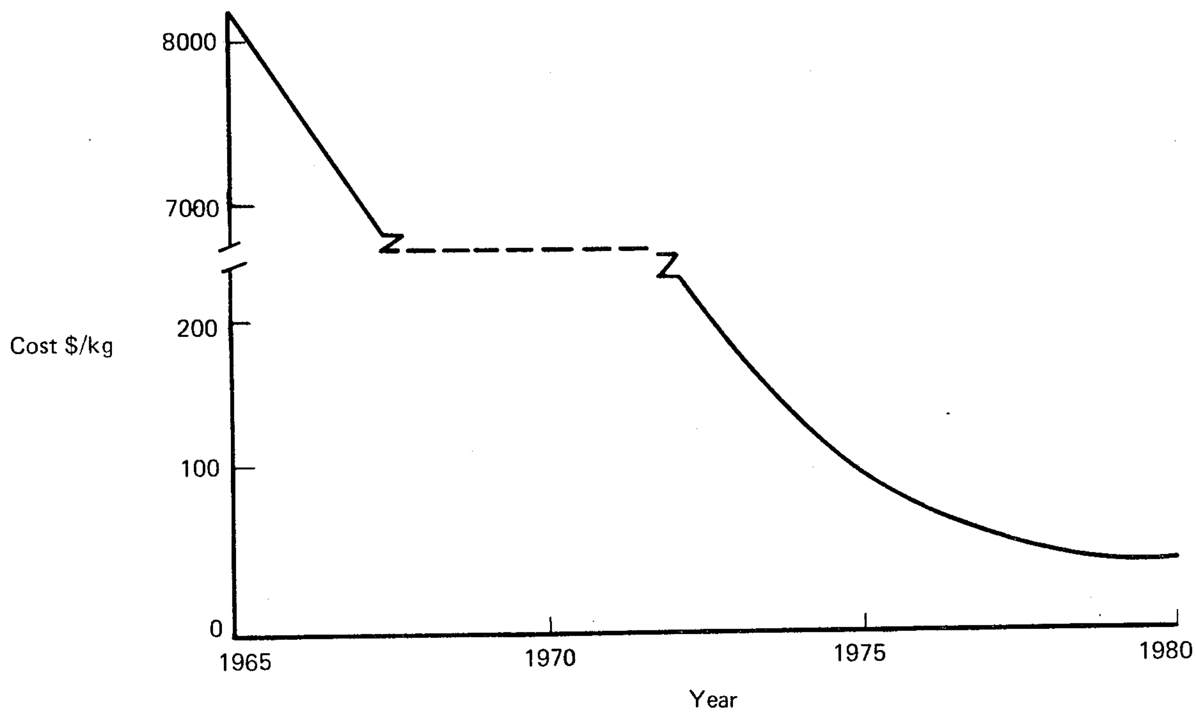

Figure 114.—Cost of Boron Filaments

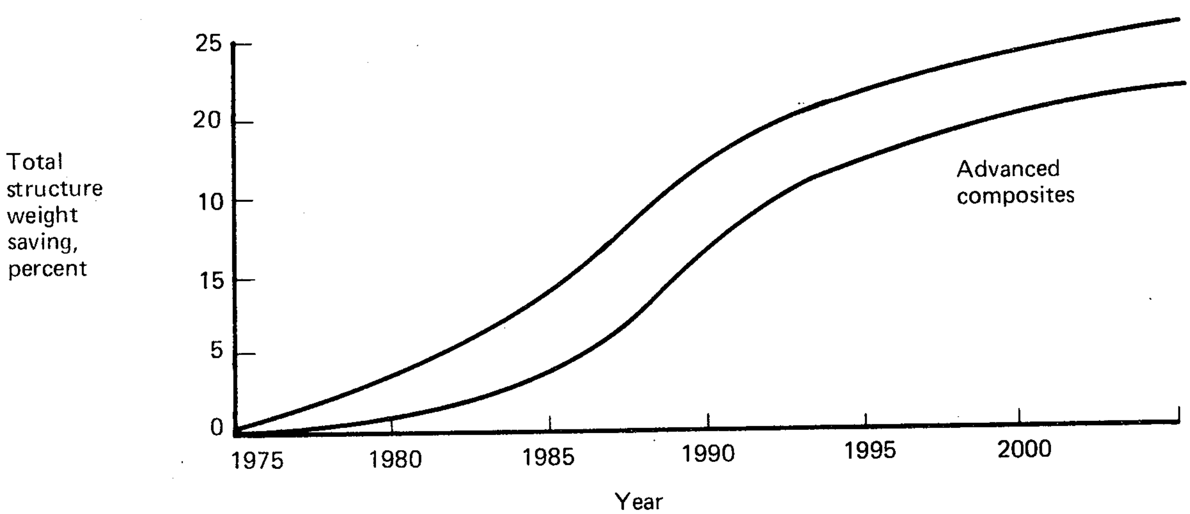

Figure 115.—Weight of Advanced Composites

mounting arrangement for the laminar flow compressors and peripheral hardware. Needless to say this additional hardware will undoubtedly contribute to increased maintenance costs.

Auto-flight systems technology has advanced dramatically since the introduction of solid state electronics. Major benefits are increased reliability, and tremendous savings in weight and bulk. With the incorporation of fly-by-wire/active controls, and laminar flow control systems, the capabilities of the autoflight systems must be greatly expanded. An advanced auto-flight system would require a network of microprocessors communicating by means of common signal busses and providing fail-safe capability by means of multiplexing. The potential for time sharing with other aircraft computers (navigation systems) may offer fail-safe capability at less cost and with a lesser weight penalty. Maintaining exotic electronic control systems will require extensive use of built-in test equipment (BITE), and ground checkout equipment that provides diagnostic fault isolation and checkout software to reduce aircraft down time. Similar maintenance support hardware requirements will also exist within the electronic repair shops.

The aircraft communications systems used in present day aircraft have suffered many growing pains with regard to the multiplex systems. The initial systems had a very high parts count that contributed to poor reliability, the systems suffered from crosstalk radio frequency interference (RFI), poor coaxial cable connections, and deep cuts and abrasions in the coaxial cable caused by poor installations. Future multiplexing systems may utilize fibre optics that will provide higher reliability, freedom from RFI, and lower installation weight.

Further advancements in solid state micro-electronics will cause reductions in weight and bulk and lessen air cooling requirements. To facilitate maintenance and reduce down time, self-test and built-in test equipment will be essential.

Aircraft instrumentation technology is currently exploiting the merits of digitally programmed video displays which can provide multiple systems monitoring capability. Video technology will eliminate numerous dials and indicators from the pilot and flight engineer's panels, providing for easier viewing, reduction of cockpit workload, and improved safety. Additionally, digital/video displays will require less electrical power, less cooling, and provide substantial weight savings. Use of digital electronics in Fault Monitoring and Detection Systems will provide for increased fault sensor usage since this system can measure both digital and analog parameters. Because of this capability, the system can measure and display system performance in and out of tolerance conditions. With an initial capability of one thousand channels (with allowance for additional growth), Fault Monitoring and Detection will become an essential asset to Maintenance Management if properly utilized. Among the apparent benefits are:

- reduced aircraft downtime due to information and diagnostics,
- minimal secondary damage and contamination of aircraft systems, thereby eliminating excessive costs,
- provides a data tracking system which can identify fleet trends with regard to equipment failures and spares usage,
- provides for improved flight safety.

Among all the changes and improvements expected in advanced technology aircraft, the Fault Monitoring and Detection System may be the most significant in controlling operating costs.

As can be expected, the landing gear systems will benefit from the reduced airframe weight caused by use of composites and advanced metals. Secondary gear structures and ancillary equipment will also benefit from composites applications.

Although carbon fibre composite brakes are in service today (limited to Concorde and some military aircraft), the airlines have not been receptive to their use due to very high initial costs and questionable performance. With further advancements in composite materials, the advanced technology airplanes will incorporate carbon brakes providing twice the wear, half the weight but probably twice the initial purchase price of equivalent metal brakes. Brake anti-skid systems will also improve, and benefit mainly from digital electronics technology which will provide exotic speed sensors and controls. Aircraft tire technology will utilize new and improved materials for tire cords and fabrics that are stronger, more heat resistant and 50% more fatigue resistant than existing materials in use today. It is likely that the new materials will increase tire life and retreadability, allowing more landings per tire and more retreads per carcass which will reduce the tire cost per landing. Historically, as tires have improved in performance, their weight has decreased; with the added benefit of composites, tire weight should continue in this trend.

It is probable that ecological constraints imposed at major airports will inhibit use of engine power for aircraft transit within the terminal area. To cope with this operational problem the airplane's main landing gear wheels could be powered by electric or hydraulic motors. The power source for this system could be the airplane's auxiliary power unit which would provide both electric and hydraulic power for ground operations. The requirements of this system could create a new maintenance requirement and also impose a weight penalty on the airplane.

The electrical power system will also benefit from the advancements in materials (composites, metals), digital controls and multiplexing. The aircraft generators may be the direct drive variable speed constant frequency (to eliminate constant speed drives and save weight) or the standard constant speed integrated drive systems. In either case, weight savings will be realized since historically the power to weight ratio (kVA/kg) has quadrupled over the past 15 years. Additionally, generator bulk size may be reduced due to advancements in electromagnetics and the reduced power requirements of the airplane's microelectronic circuitry. Power generation control circuitry will employ the use of multiplexing,and digital electronics for control, monitor and fault detection. Since extensive use of microelectronics within the airplane reduces the system's power loading, generator cooling requirements will decrease and should effect improved reliability.

Hydraulic systems requirements are likely to diminish because of the probable incorporation of the fly-by-wire concept on the advanced technology airplane. With the elimination of the hydraulic actuators, the control valves and associated hardware in the flight controls system, a substantial weight savings will be realized. Weight savings will also be achieved in providing welded tubing joints to the maximum extent practical. The use of welded tubing joints will reduce maintenance costs as hydraulic tubing joint leaks are very difficult to isolate and repair (one U.S. airline reports that in one year its fleet lost 37 850 liters of skydrol through leakage and plumbing failures). Welded tube joints will improve system reliability, but their use will create some new maintenance problems when considering repair of damaged plumbing within the airplane. Hydraulic fluids, mineral base, petroleum base of skydrol derivatives as used today may not be compatible with the environment of composite structures and consequently, the new fluids that will be developed may well increase in cost.

The aircraft fuel system like the hydraulic system will encounter new problems regarding the interface of jet fuel and aircraft composite structures. Present tank sealing techniques may well be revised to accommodate the use of new sealing materials. The transition from fossil fuel energy sources to liquified gasses will have the most dramatic impact on aircraft fuel systems technology. New problems will appear with regard to fuel handling, fuel storage and in particular, personnel and systems safety. Practical development and implementation of a gaseous fuel system may well occur with the third or fourth generation advanced technology airplane.

Maintenance Management.—Historically, aircraft maintenance philosophy was edicted by Federal regulations and directives, and evolved in the mid-1930's. Initially, all maintenance tasks were predicated on a certain number of hours flown and at the identified expiration time aircraft, engines, and components were removed from service and overhauled. This system defined a so called Hard Time Maintenance Program.

In the late 1940's the airline operators and the Federal Government mutually agreed, and believed, that in many cases reliability and safety could be sustained by evaluating periodic physical checks and measurements of the aircraft and its components against standards defined in the Hard Time Maintenance Program. This concept was called On-Condition Maintenance and became an approved maintenance process. Both On-Condition and Hard Time are considered preventive maintenance processes, and either process could be employed by the airline operator.

The FAA issued Advisory Circular AC120-17 in 1965 which made the airlines responsible for establishing their own maintenance programs if their programs met or exceeded the Reliability and Safety Standards established by the FAA. Essentially, Advisory Circular AC120-17 established a reliability monitoring maintenance program which is a maintenance program based on predicted failure rates and intervals.

During the 1970's wide body aircraft entered airline service and another maintenance program evolved called Condition Monitoring. This maintenance program, as its name implies, provides a method for monitoring the conditions of aircraft, engines, and components essential to the safe and reliable operation of an aircraft.

In summary:

> Hard Time—a maximum interval for performing maintenance tasks. These intervals usually apply to overhaul but can also apply to total life of parts or units.
>
> Reliability Monitoring—based on the premise that an item will perform a required function under specified conditions, without failure, for a specified period of time.
>
> On-Condition—repetitive inspections or tests which determine the condition of units, systems or portions of structures.
>
> Condition Monitoring—accomplished by appropriate means available to an operator for finding and resolving problems. To be placed on condition monitoring, a unit must not adversely affect operating safety.

Other maintenance concepts are also in effect and approved by the FAA. In general, they are tailored to the requirements of the respective airline. Calendar Overhaul for example is one maintenance concept whereby aircraft are phased into an inspection cycle at definite calendar intervals regardless of time left on the airplane before an equivalent hourly check is due. This method is more cost effective to some operators as it tends to provide for better manpower utilization and improved planning capability that reduces airplane down time.

In retrospect, airframe maintenance costs have been reduced or controlled to an acceptable level. This has been primarily achieved by continuing product improvements and implementation of sound maintenance management programs.

Impact of Advanced Technology Airplane.—Introducing an advanced technology airplane into airline service will undoubtedly create many new maintenance problems that will affect overall airline economics. Of paramount importance to the operator is minimal aircraft down time, since loss of productivity minimizes the return on investment of a very expensive piece of capital equipment. In order to achieve maximum airplane utilization, the airframe manufacturers, the airlines, and the Federal Aviation Administration must, through joint cooperation, exploit the benefits of the best maintenance management programs, establish at least a 95% on-condition rate for aircraft components. and maximize the capability of on-board systems monitors and fault detection equipment.

Previous experience with new introductory airplanes indicates that within 3 to 4 years a maturity level is attained when maintenance costs tend to stabilize. First generation advanced technology aircraft incorporating 10 to 15% composite structures should also reach maturity levels within the same time frame (3 years). The success in achieving this goal lies heavily with the airframe manufacturer who must insure that the operator's personnel are adequately trained, that new technology maintenance procedures are provided, that the necessary new support equipment is developed, and that adequate spares are provided. In addition, the airframe manufacturer must be willing to supply technical assistance to the operator and recognize the importance of warranty claims that usually identify impending hardware deficiencies within the airplanes' systems. The airline operators, being heavily burdened with the purchase of the advanced technology airplane, may seek ways and means to reduce operating and maintenance costs by standardizing airplane configurations, pooling high cost spares, and establishing interline maintenance agreements.

Conclusion.—This study has provided an in-depth analysis relative to the airframe maintenance costs as incurred by American Airlines, and supported in some instances with other airline data which was provided by various sources to The Boeing Company. As the data sources provided both labor and material costs for each aircraft system (as identified by ATA Specification 100), it was possible to illustrate the relative costs for a number of aircraft types, and their relationship to each other with respect to certain parameters as previously identified. In many cases the data points do not provide for the best correlation. This is to be expected as there are many variables that can affect the consistency in accounting methods between airlines, and even within an airline, with respect to airplane types.

Although the derived formulation in this document was used to illustrate the maintenance costs for an advanced technology aircraft (TAC/Energy airplane), it should be noted that these cost estimates are based on parameters that are relevant to present technology.

Since future airplane systems may not readily identify with present technology, new parameters must be developed to enhance maintenance cost forecasting. Also maintenance management techniques will change to cope with rising costs, and will undoubtedly affect maintenance technology.

4.5 SCHEDULE DELAYS AND CANCELLATIONS

An airline's on time dispatch reliability is of importance in the measure of its acceptability to the travelling public. In addition, dispatch reliability is a means by which the CAB judges the performance of an airline in its response to CAB objectives and passenger needs. As a result, considerable effort is expended by the airline marketing and operations departments ensuring that flight schedule delays and cancellations are kept to a minimum.

It is difficult to assess the total economic influence that delays and cancellations have on an airline's operating costs. However, most airlines assign cost coefficients which endeavor to account for the financial impact of such items as extra flight crew costs, additional passenger handling costs and lost passenger revenue. In addition, there may be more tangible expenses in the form of the charges incurred correcting the delay or cancellation cause, particularly if it is mechanically oriented.

These additional expenses are not specifically segregated for each delay and cancellation, but are accrued in the normal CAB and airline account codes for the specific task or function. For example, the maintenance costs associated with correcting mechanical delays are included in the Direct Maintenance Cost (DMC) of section 4.4.6.

The purpose in assigning cost coefficients to specific items of delay and cancellation causes is to provide a means of determining which of these causes are the most influential and establish a system of priorities for corrective action, particularly in areas where the airline has a degree of control.

Aircraft design technology can influence the number and causes of delays and cancellations, not only as a result of product design improvements (or lack thereof), but through system design redundancies. These system design redundancies permit, for example, the dispatch of an aircraft with a specific function inoperative, for a given flight segment(s), without an adverse effect on equipment safety.

If it were not for these system design redundancies, aircraft delays and cancellations for mechanical reasons would be a more significant portion of aircraft direct maintenance costs than the 3% to 5% they represent in American Airlines and other airline operations today.

Delays and cancellations for nonmechanical reasons such as late aircraft arrivals, weather, air traffic control, etc., over which an airline has little control, tend to be of shorter duration than their mechanical counterparts, but more frequent. These nonmechanical causes are assessed to represent in American Airlines an expense equivalent to approximately 25% of annual airframe direct maintenance costs or, approximately 15% of annual aircraft direct maintenance costs. They can also be greatly influenced by the frequency of service offered by the airline, its theatre of operations and the time of year.

An analysis of the causes of delays and cancellations by category are included as Appendix VI. A suggested approach to developing a model for predicting delays and cancellations at the ATA system level will be found in Appendix VI.

4.6 COST ASSESSMENT METHOD

The foregoing correlations and analyses of operating cost experience data has provided the basis for the following operating cost assessment method. In general, operating cost elements appear to relate to design or technology characteristics. Many of the expense elements have a definitive correlation with these design and technology characteristics, such as fuel expense or maintenance expense which are in turn directly relatable to the technological parameter of weight, complexity, performance and reliability. There is another general class of operating cost elements that are indirectly related to technical characteristics by somewhat arbitrary agreement or convention. For this later group, caution should be exercised in assessing validity of the implied technology interactions.

This operating cost assessment methodology accounts for all aircraft related cost elements including the costs of delays and cancellations discussed in section 4.5. The costs have been modeled on a cost-per-flight basis as this was found to be the best direct common denominator since the summation of the cost elements can be readily converted to costs per flight hour, block hour, or per distance flown as desired by the particular user. In making the conversions it should be recognized that the fuel expense and direct maintenance costs are a function of total hours flown, while the trips per year used to normalize depreciation and insurance are revenue trips. This is approximately 2% nonrevenue flying.

4.6.1 COST ELEMENTS INDIRECTLY RELATED TO TECHNOLOGY

Details of how the various cost elements were derived can be found in the preceeding chapters.

Depreciation

The depreciation per trip equals the annual depreciation value of the cost of flight equipment plus spares inventory divided by the number of flights per year.

Depreciation per trip = (A (1 + 0.04) + ExNx(1+0.30)) x 0.90/(14 years x TRIPS)

Depreciation schedule = fourteen (14) years to 10% residual

Number of trips per year (TRIPS) = 3205/(FL + 0.327)

Depreciation = (0.0669xA + 0.0836xExN) x (FL + 0.327)/3205

where the required inputs are

A = airframe price $
E = engine price (per engine) $
N = number of engines per airplane
FL = flight length, flight hours per flight

In a competitive environment the price of the aircraft equipment is related to the cost of manufacturing. Technology which changes relative aircraft size, costs of materials and components, and improves manufacturing processes could therefore affect airframe or engine prices and thereby affect the depreciation expense. However, it can also be reasoned that when comparing alternative aircraft designed to a common specification (i.e., range, payload, or other measure of productivity) the more efficient aircraft in terms of its cash operating costs, e.g., fuel consumption, maintenance, etc., is more valuable to the operating airline and therefore would demand a higher price without regard to its relative cost of manufacturing (a form of compensation for the manufacturer for achievement in developing and producing a superior aircraft). From this it does not appear that a technology/price relationship can be modeled. Further, it is suggested that, as the price is in part dependent upon the cash operating costs and design, comparisons would be more meaningful if not clouded by pricing estimates and arbitrary depreciation schedules.

The spares portion of the investment cost is the cost of the spares inventory as distinct from the parts consumption cost included in the maintenance expense.

Insurance

The annual relative insurance cost divided by the number of trips per year equals the insurance expense per trip.

Insurance expense per trip = (1% airplane price) x (FL + 0.327)/3205. In this application, the airplane price does not include spares.

Flight Crew Pay—Domestic Operations

The cost of the flight crew pay (three member crew) per block hour = 174 + 0.452 x (airplane maximum gross weight in kg)/1000.

The cost per trip = 174 x FL + 43.50 + (0.452 x FL + .11299) x(MGW/1000), (MGW in kg)

For a two member flight crew use 75% of cost of three member crew.

While airplane gross weight and speed are technological parameters used in crew pay formulas, they are arbitrarily assigned factors in an endeavor to account for productivity, etc. The relative value of these technical factors is, in practice, clouded by the nontechnical factors such as seniority. The cost assessment model formulation assumes that the apparent correlation of seniority with gross weight is valid and that speed effects compensate for reasonable variations of trip distance per flight hour.

Flight Attendant Pay

The cost of flight attendants per trip is related to the number of seats and the average flight length.

Flight attendant expense per seat flight = $0.691 \times FL + 0.00175 \times FL^2$

Landing Fees

The landing fees are determined by the bonded indebtedness of the airports, which is arbitrarily assessed to the airplane as a function of aircraft weight in kgs (most frequently maximum landing weight).

Landing fees per departure = 1.54 x MLW/1000.

Fuel Servicing Fees (excluding the cost of fuel)

Like the landing fees, fuel servicing fees are subscribed to by airlines to cover the indebtedness with respect to the fueling facilities. It is a function of the airports served by the airline and independent of the level of service, the characteristics of the aircraft and/or the quantity of fuel consumed by the airplanes of the fleet.

Introductory Costs

The introductory cost associated with training (flight crews and maintenance crews) are primarily fleet size oriented and were not found to be quantitatively generalized in terms of technological or operational parameters.

Aircraft Control Fees

The airlines shared cost for the Aeronautical Radio Incorporated (ARINC) communications network = $7.00 per flight (current system). This expense could be reduced to about $4.00 (1976 $) when aircraft are equipped with data link.

Aircraft Servicing

Aircraft servicing is cleaning the aircraft, preparing the galleys, checking the logs, etc.

Aircraft servicing per flight:

Narrow body aircraft:

Manhours = 0.02 x seats
Materials $ = 0.002 x seats

Wide body aircraft:

Manhours = 0.033 x seats
Materials $ = 0.003 x seats

4.6.2 COST ELEMENTS DIRECTLY RELATED TO DESIGN AND TECHNOLOGY

Fuel

The aircraft fuel consumption is a direct result of the overall airplane performance which can only be related to technology through the design definition and performance analysis process. The design performance definition is a required input for assessing the fuel expense. Operational experience has indicated that the design performance defined fuel consumption should be increased by approximately 4% to account for average flight operations of mature airplanes, and to put it in context with the other expense items.

Aircraft Direct Maintenance Expense

The aircraft direct maintenance expenses have been modeled at the ATA systems level, a systems group level and an overall airframe and propulsion system level. At each level the labor and materials expense have been modeled separately to permit appropriate application of cost escalation factors. It is intended that the overall assessment method be used to determine a baseline maintenance expense estimate and then the adjustments applied for technology differences from the current levels assumed in the baseline for each affected ATA system. The baseline model accounts for the interactions of the system alternatives on the overall airplane. The system level adjustment need only involve the system(s) where there has been a known departure from current state-of-the-art.

The model for the overall airframe (airplane minus propulsion systems) is presented in two forms associated with different degrees of design detail definition. Either of these forms will produce an assessment commensurate with the detail of the baseline assumptions.

The more detailed baseline assessment method is shown on table 12 for maintenance labor and material costs (1976 $). The short form airplane system maintenance cost assessment is contained in table 14.

The introductory maintenance costs for new aircraft models appears to be partly compensated for by the warranty provisions and the normal maintenance expenses time lag. Without warranty provisions, introductory costs for new airplanes would have been higher than was actually experienced. For derivative aircraft models and/or new models of the same type, the same warranty provisions and phase lag result in a first four year average maintenance expense of about 70% of the mature rate.

Propulsion System Maintenance (ATA Systems 71 through 80)

The propulsion systems maintenance cost method has been adapted directly from the methods developed in reference 1. The format has been changed to be consistent with the presentation of the airframe systems.

The Long Form Method for estimating the propulsion systems maintenance cost has been based on a module-by-module analysis of the engine removal rates (frequency of shop visits) and the cost of repair in manhours and materials (cost per shop visit). This method requires a detailed description of the engines' six modules, including pressures, temperatures, diameters, rotor tip speeds, number of stages, and prices. As this level of detail is usually not available during design conceptual studies or preliminary design studies, the Short Form Method was developed which sacrifices sensitivity for simplicity, but still represents a reasonable assessment tool.

Long Form Method

The Long Form Method shown in table 15 is based on the basic engine shop repair cost for the six engine modules, plus an estimate of the lesser costs of the installation, tear down and build up, starter, thrust reverser, and other accessory maintenance. The six basic engine modules are as follows:

Table 14.—Direct Maintenance Cost (DMC) Short Form

DMC = cyclic labor \$ + hourly labor \$ + cyclic material \$ + hourly material \$ cost per flight hour is given by:

Cost per flight hour is given by:

Cyclic labor \$ = [11.720 + .01479 AFW/10^3 + .00344 AC kg/min + .48656 (N) CHANN + .00538 SEATS + .00049 (N) GEN x KVA + .02277 SEATS x CF + .0396 x [(N) ENG + APU] + .04672 MGW/10^3 + .00066 kg FUEL/10^3 + .00050 HYD LPM + .34564 (N) INS + .58923 CF + .00001 AC kg/min x THRUST/10^4 + .0306 (N) POD NAC] /FL

Hourly labor \$ = 15.985 + .17090 AFW/10^3 + .004753 AC kg/min + .70018 (N) CHANN + .00856 SEATS + .00139 (N) GEN x KVA + .01609 SEATS x CF + .0132 x [(N) ENG + (N) APU + .01164 MGW/10^3 + .001023 kg FUEL/10^3 + .000472 HYD LPM + .70175 (N) INS + 1.19631 CF + .000005 AC kg/min x THRUST/10^4 + .1224 (N) POD NAC + (APU SHP x APU kg/min)$^{1/2}$ (.0003) + .7185] $1.24e^{-17FL}$ x (N) APU

Cyclic material \$ = [6.335 + .00055 AFW/10^3 + .00247 AC kg/min + .8657 (N) CHANN + .00707 SEATS + .00071 (N) GEN x KVA + .01731 SEAT x CF + .0301 [(N) ENG + (N) APU] + .11892 MGW/10^3 + .00031 kg FUEL/10^3 + .00118 HYD LPM + .19751 (N) INS + .60486 CF + .00010 AC kg/min x THRUST/10^4 + .01265 (N) POD NAC + .00014 wing] / FL

Hourly material \$ = 5.845 + .00348 AFW/10^3 + .00342 AC kg/min + .12457 (N) CHANN + .01628 SEATS + .00202 (N) GEN x KVA + .01294 SEAT x CF + .010 x (N) ENG + (N) APU + .02897 MGW/10^3 + .00481 kg FUEL/10^3 + .00274 HYD LPM + .4010 (N) INS + 1.22805 CF + .00003 AC kg/min x THRUST/10^4 + .05058 (N) POD NAC + .00013 wing + [(APU SHP x APU kg/min)$^{1/2}$ (.00073) + 1.466] $1.24e^{-.17FL}$ x (N) APU

The above is a baseline equation, i.e.,

1. Multiplex not installed,
2. Conventional oxygen system installed,
3. Simple single spool auxiliary power unit installed,
4. Conventional (noncurved) windwhields installed, and
5. Single circuit engine fire detection loops installed.

(Abbreviations are defined in table 11, page 93)

Table 15.—Propulsion Systems Maintenance Costs (Long Form Method)

(per engine 1976 $)

Mean time between repair – hours (MTBR)

= 0.83 x critical module MTBR of table

Basic engine maintenance shop costs

Labor manhours/flight

$$= \left[\sum_{o}^{6 \text{ modules}} (\text{manhours/repair})/\text{MTBR} + .19 \right] \times 1.064 \times FL^{0.72}$$

Maintenance materials/flight

$$= \left[\sum_{o}^{6 \text{ modules}} (\text{materials/repair})/\text{MTBR} \right] \times 1.18 \times FL^{0.72}$$

Propulsion systems outside service costs

= 0.065 x basic engine shop materials

+ 0.195 x basic engine direct labor $

Other propulsion systems maintenance costs

Labor manhours/flight

$$= 0.0440 + 0.143 \times FL + \left[FL^{0.72} (280 + 0.075\, W_e)/\text{MTBR} \right]$$

if not core reverser subtract (0.0188 + 0.0612 FL)

Materials/flight

$$= 0.326 + 0.829 \times FL + (0.00383 \times E\$ \times FL^{0.72}/\text{MTBR})$$

if no core reverser subtract (0.131 + 0.331 FL)

To estimate maturity effect use the following factor on mature levels (as calculated above) for first five year average:

MTBR	$(2.2)^{-1}$
Manhours/repair	0.7
Materials $/repair	0.7

Note: These equations differ from those published previously in NASA Report NASCR 134645 reference 1 in that they have been updated to reflect:

1. 1976 $
2. Metric units
3. Outside services calculated using direct labor in lieu of fully allocated labor
4. Cost per flight departure in lieu of cost per flight hour.

Table 16.—Basic Engine Module Maintenance Cost Forecasting—Long Form Method

Kelvin

Module	Mean time between repair—hours	Manhours per repair	Materials cost per repair—$
Fan/low compressor	$4410/Y_{LPC}^{0.874}$	$95 \times Z_{LPC} + 33$	0.125 x module price
High compressor	$4410/Y_{HPC}^{0.874}$	$95 \times Z_{HPC} + 33$	0.114 x module price
Diffuser	5000	175	0.164 x module price
Combustor	$-2.25 \times Y_{CBS} + 4500$	250	0.124 x module price
High turbine	$-711 \times Y_{HPT} + 5650$	$1.78 \times Z_{HPT}^{0.611}$	0.238 x module price
Low turbine	$-711 \times Y_{LPT} + 5650$	$1.78 \times Z_{LPT}^{0.611}$	0.089 x module price

where:

$$Y_{LPC} = T_3 \times \left(P_3/P_2\right)^{1/N(LPC)} \times U_{LPC} \times 10^{-6}$$

$$Z_{LPC} = \left[\left(U^2_{FAN} \times D_{FAN} \times N_{FAN}\right) + \left(U^2_{LPC} \times D_{LPD} \times N_{LPC}\right)\right] \times 10^{-8}$$

$$Y_{HPC} = T_4 \times \left(P_4/P_3\right)^{1/N(HPC)} \times U_{HPC} \times 10^{-6}$$

$$Z_{HPC} = U^2_{HPC} \times D_{HPC} \times N_{HPC} \times 10^{-8}$$

$$Y_{CBS} = T_5 - T_4$$

$$Y_{HPT} = T_5^{0.5} \times P_5/P_6 \times U_{HPT} \times N_{HPT} \times 10^{-5}$$

$$Z_{HPT} = T_5^{0.5} \times D_{HPT} \times N_{HPT}$$

$$Y_{LPT} = T_6^{0.5} \times P_6/P_7 \times U_{LPT} \times N_{LPT} \times 10^{-5}$$

$$Z_{LPT} = T_6^{0.5} \times D_{LPT} \times N_{LPT}$$

Fan and low pressure compressor module	FAN/LPC or LPC
High pressure compressor module	HPC
Diffuser module	DIF
Combuster module	CBS
High pressure turbine module	HPT
Low pressure turbine module	LPT

The engine module maintenance cost forecasting method is contained in table 16.

The required dimensional characteristics are as follows:

CET	Combustor exit temperature T_5 K
Dxxx	Diameter, inches subscripts or 0.3937 x diameter cm subscripts LPC – first stage blade tip HPC – first stage blade tip HPT – first stage blade tip LPT – first stage blade tip FAN – fan blade tip
ES	engine price in 1976 $
MTBR	mean time between repair or removal
Nxxx	number of stages in module xxx except subscript LPC – number of stages in fan plus number of stages in low pressure compressor
Px	pressure, newtons per sq. m absolute, sea level takeoff, hot day
Tx	temperature, degree K, sea level takeoff, hot day subscripts 2 – LPC inlet 3 – LPC exit 4 – HPC exit 5 – combustor exit 6 – HPT exit 7 – LPT exit
Uxxx	tip speeds, ft/sec, 0.3045 m/sec, sea level takeoff, hot day (use first stage blade tip except for U(LPC) - FAN/LPC module use weighted average blade tip speed).

Short Form Method

The short form method shown in table 17 requires, as input, the number of engines, the engine price, combustor exit temperature, bare engine weight, and labor rate.

4.6.3 STATEMENT OF THE METHOD

The total airplane related operating costs for domestic service may be stated as follows:

$$\text{Depreciation} = \frac{\text{Purchase price* – residual}}{\text{Depreciation period}} \times \frac{1}{N}$$

Table 17.—Propulsion Systems Maintenance Costs—Short Form Method

(per engine 1976 $)

Mean time between repair—hours (MTBR)

$$= 3604/e^{0.000324 \times CET} \times FL^{0.28}$$

Labor manhours per flight

$$= 0.0440 + 0.143\,FL + \left[FL\left(1936 + 0.705 \times W_e\right)/MTBR \times FL\right]$$

if no core reverser subtract (0.0188 + 0.0612 x FL)

Materials $ per flight (for high by-pass ratio engines)

$$= 0.326 + 0.829 \times FL + 0.0906 \times E\$/MTBR \times FL$$

if no core reverser subtract (0.131 + 0.331 x FL)

To estimate maturity effect use the following factors on mature levels (as calculated above) for first five year average:

MTBR	$(2.2)^{-1}$
Manhours/flight	1.42
Materials $/flight	1.42

where:

CET	=	Combustor exit temperature, K
E$	=	Cost of engine
MTBR	=	Mean time between removals
W_e	=	Weight of engine

Note: These equations differ from those published previously in NASA Report NASCR 134645 reference 1 in that they have been updated to reflect:

1. 1976 $
2. Metric units
3. Outside services calculated using direct labor in lieu of fully allocated labor
4. Cost per flight departure in lieu of cost per flight hour

+	Insurance	$= \frac{1\% \text{ of purchase price}\dagger}{N}$	
+	Control fee	= \$7.00 without data link or	
		= \$4.00 with data link	
+	Landing fee	= \$1.54/1000 kg of landing weight	
+	Aircraft servicing		
	Narrow body	= 0.02 x seats x \$9.50/man-hour	(labor)
		+0.002 x seats	(material)
	or		
	Wide body	= 0.033 x seats x \$9.50/man-hour	(labor)
		+0.003 x seats	(material)
+	Flight attendant pay	$= 0.691 \times FL + 0.00175 \times (FL)^2$	
+	Flight crew pay**	$= 174 \times FL + 43.5 + (0.452 \times FL + 0.11299) \times \frac{MGW}{1000}$ kg	
+	Fuel expense	$= \frac{\text{Liters}}{\text{Trip}} \times \frac{\text{Dollars}}{\text{Liters}}$	
+	Maintenance cost	See section 4.4.5	

where FL = Flight length, hours

$$\text{Utilization} = N = \text{Number of departures per year} = \frac{3205}{FL + 0.327}$$

*Including airframe and engine spares

**The expression given is for a 3 man crew—for a two man crew, use 75% of this value.

†Does not include airframe and engine spares.

4.7 COST ASSESSMENT METHOD VALIDATION

Most elements of the operating cost assessment method have been validated by their development where the data base form was in the same context as the assessment method formulation such as crew pay, flight attendant pay, landing fees, etc. It was believed necessary in this section to show the relationship of the assessment method to actual aircraft expenses where the method resulted from the integration of a number of detailed correlations such as was the case with the maintenance expense and the cost of schedule delays and cancellations. As the latter operating expense is included within the other expense elements of the operating cost assessment model, they represent a separate assessment method and have been verified in Appendix VI.

5.0 OPERATING COST ASSESSMENT OF ADVANCED AIRCRAFT

As an example of the use of the operating cost assessment methods, two aircraft were selected from reference 3, the TAC/Energy airplane representing a design incorporating advanced technology as some unusual design features and second, the CWB-E, a contemporary conventional design with the same design payload range capability.

The TAC/Energy design included advanced structural materials (unidirectional composites and bonded aluminum), a high capacity brake system, high speed turnoff gear, programmed flaps to attenuate wake turbulence, advanced electronics, powered wheels, and advanced propulsion system features for emissions and noise.

Table 18 contains a summary of the design characteristics pertinent to the long form baseline estimate.

The comparable aircraft related operating costs are shown in table 19. Figure 116 shows a breakdown of airframe costs calculated by the parametric (current study) method. These systems are grouped as follows:

Inspections	ATA System 99
Airframe	27, 28, 32, 50 through 57
Avionics	22, 23, 31, 34
Equipment and furnishings	21, 25, 26, 30, 33, 35, 36, 38
Secondary power	24, 29, 36, 49

Table 20 compares operating cost assessments by the study methods with the 1967 ATA method and with a manufacturer's 1976 update of the ATA method.

Consistent values for labor rates ($9.50 per hour, $2.30 burden factor), fuel price ($0.074 per liter, $0.28 per gal) and the 1967 ATA flight crew pay (escalated per the labor rate escalation factor) were used.

The airframe maintenance expense as projected by these three methods are compared in figure 117. It is apparent that the manufacturer's updated method, based on regressions of current experience, and the new method agree well for the conventional state-of-the-art CWB-E airplane, and for the TAC/Energy airplane. The study method attempts a reasonable accounting for deviations in conventional design approaches and/or the incorporation of advanced technology as shown by the assessment of the airframe maintenance of the TAC/Energy airplane.

The sensitivity of the TAC/energy airplane airframe maintenance projection on the advanced technology relative maintenance factor for the affected ATA systems are as follows:

- A 20% increase in landing gear maintenance complexity factor increases airframe total maintenance by 2.41%.
- A 50% increase in fuselage, empennage, and wing maintenance complexity factor increases the airframe total maintenance by 1.88%.

- The 50% reduction in the INS maintenance reduced the total airframe maintenance by 1.83%.

- The increase in the autopilot complexity (56%) causes an increase in the total airframe maintenance of 0.88%.

- A reduction in APU power to that of the CWB-E would reduce the TAC/Energy airframe maintenance by 5.26%.

It is not the intent of the methodology to suggest that the projected maintenance expense is unavoidable: understanding maintenance expense is the first step in avoiding it.

Table 18.—Summary of Airplane Characteristics

	Conventional wide body airframe	TAC/energy airframe
Flight length in hours	2.3	2.27
Airframe weight in kg	72 400	58 200
Air conditioning total capacity in kg		
Air flow per minute	150	150
Number operating autopilot channels	2	2
Number design seats	196	196
MUX installed		
Number inflight-operated electric generators	3	4
KVA rating of full time generators	270	300
Design complexity factor (.6, 1., 1.6)	1.6	1.6
Engine thrust in newtons per engine	144 100	67 600
Number engines	3	4
Total fuel capacity in kg	54 400	44 900
Total LPM of full time hydraulic pumps	863	560
Maximum gross weight in kg	147 200	118 300
Number of INS installed	0	0
Individual oxygen generators used		
APU spec. air flow in kg per minute	141	175
APU spec. shaft horsepower—watts	85 760	126 770
APU complexity factor (1.0 to 1.8)	1.8	1.8
APU operating hours per APL flight hour	.839	.843
Number podded nacelles	3	4
Conventional windshield used		
Wing area in sq. m.	273	199
Engine weight—each (kg)	2 690	1 065
Engine combustor exit temperature (K)	1 500	1 566
Airframe price	$16 346 000	$14 865 000
Engine price—each	$ 979 000	$ 680 000

Table 19.—Operating Cost Comparison—TAC/Energy and CWB-E—
Cost Per 1852 km (1000 nmi) Flight

	TAC/Energy	CWB-E
Fuel	759.45	1068.70
Maintenance		
Airframe	249.99	252.86
Propulsion system	296.05	296.45
Burden	509.80	502.14
Flight crew pay	569.80	613.41
Flight attendant pay	309.20	313.32
Aircraft servicing		
Direct	62.04	62.04
Burden (2.3 x labor)	141.33	141.33
Landing fees	151.80	195.44
Aircraft control fees (air ground communications)	7.00	7.00
Insurance	142.39	158.06
Cash operating costs	3197.57	3610.75
Depreciation	988.78	1096.96
Total	4186.35	4707.71
Flight length	2.269	2.30
Trips/year	1235	1220

*Table 20.—TAC/Energy Operating Cost Assessment—
Cost/Trip for 1852 km (1000 nmi) Range Flight*

Operating cost element	Study assessment	1967 ATA	Updated method
Fuel @ $0.074/hr ($0.28/gal)	759.45	744.84	744.84
Maintenance			
Airframe			
Materials	112.44	196.64	101.07
Labor @ 9.50/hr	137.55	219.33	127.43
Propulsion system			
Materials	213.03	208.69	356.21
Labor @ 9.50/hr	83.02	603.22	380.90
Maintenance burden total	509.80		
Flight crew pay	569.80	833.46	733.46
Flight attendant pay	309.20	–	272.28
Aircraft servicing			
Materials	0.59	–	–
Labor @ 9.50/hr	61.45	–	105.94
Burden	141.33	–	–
Landing fee	151.80	–	79.71
Aircraft control fee	7.00	–	9.00
Depreciation	988.78	1103.78	802.20
Insurance	142.39	115.54	121.86
Utilization			
Block hour/year	3110	3830	3635
Trips/year	1235	1522	1443

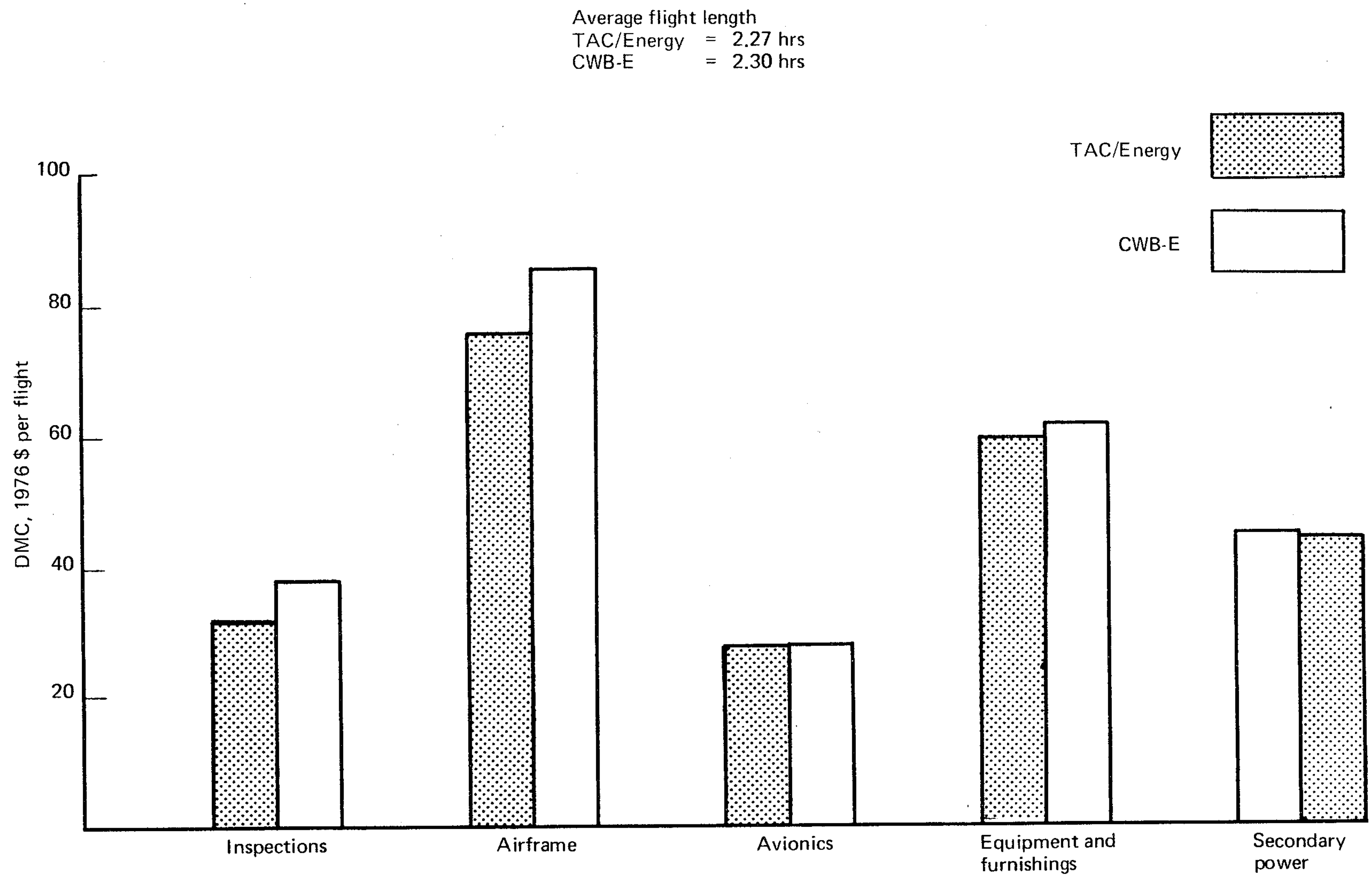

Figure 116.—Airframe Maintenance Cost Comparison

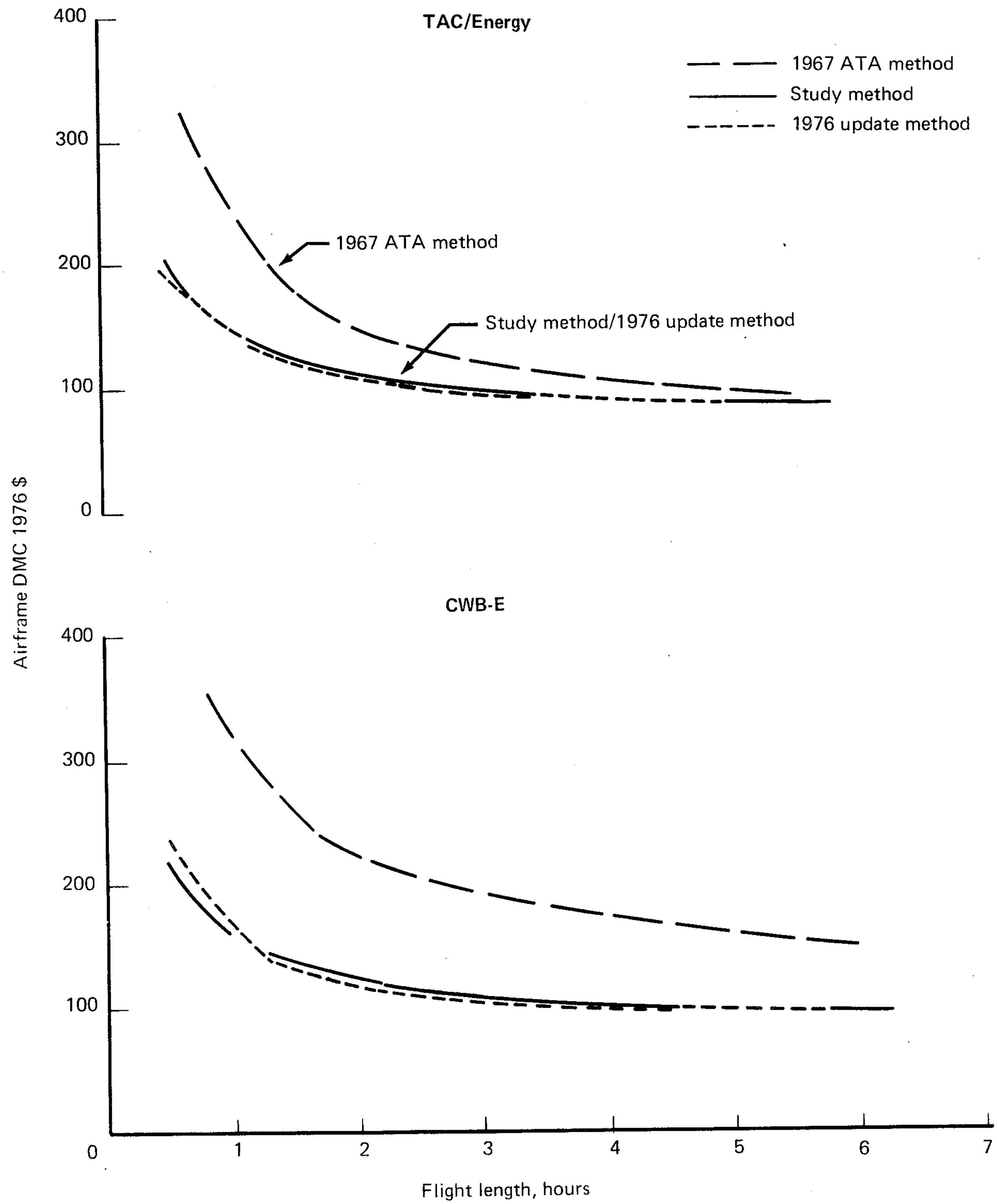

Figure 117.—Airframe Maintenance Method Comparison

6.0 PARAMETRIC ANALYSIS

The study of operating cost assessment methodology has shown that fuel and maintenance expense are the main expenses that have a cause-and-effect relationship to technology.

A 50% reduction in the design range from 5556 km (3000 nmi) to 2778 km (1500 nmi) at 2778 km improves the seat km per unit of fuel by 4.5%. See figure 40.

The sensitivity of fuel consumption to other than aircraft scale (design seat capacity) is as follows:

A 10% reduction in the example baseline airplane weight factors results in the following improvement in seat km per unit of fuel after the configuration is recycled: (see figs. 41, 42, 43, 44, and 45).

Body weight	1.6%
Wing weight	1.4%
Engine weight	0.5%

A 5% drag improvement reduces the block fuel by 5.9% (see fig. 44). A 10% improvement in specific fuel consumption reduces the block fuel by 10% (see fig. 45).

7.0 RESEARCH AND TECHNOLOGY RECOMMENDATIONS

7.1 RESEARCH AND TECHNOLOGY RECOMMENDATIONS

This in-depth investigation into the sources of airline operating expenses has suggested a number of areas for further research activity.

7.1.1 SAFETY

A large portion of crew workload and airplane equipment is related to maintaining and improving high levels of safety. A reduction of workload through the use of simple and effective systems and procedures, coupled with the reliable automation of such systems, could maintain or improve on current levels of safety. This should contribute to reduced system ownership costs (acquisition and maintenance) and provide the potential for reducing on-board labor costs (fewer crew members) associated solely with safety.

Example: Automated emergency egress facilities (e.g., doors and slides) and hazard detection and warning systems (e.g., ground proximity warning systems, separation assurance).

It is recommended that NASA undertake the requisite research and development programs to ascertain the feasibility and cost impact of such safety oriented workload changes.

7.1.2 FUEL CONSUMPTION

Fuel consumption will continue to be a major cost element in transport airplane operations. The need for significant gains in passenger kms per unit of fuel consumed through reductions in drag and weight (in addition to improvements in engine thrust specific fuel consumption) cannot be overstated. However, any gains must not be made at the expense of decreased safety, reliability and/or maintainability, or increased maintenance costs. Suggested areas for continued research and development efforts are:

a. Lightweight structures—metallic and composites.

b. Avionics and controls—lighter weight systems and smaller/lighter aerodynamic control surfaces.

c. Airframe drag reduction—at the design stage and throughout the airplane's useful life.

d. Cabin pressurization by means other than primary engine bleed air.

7.1.3 DIRECT MAINTENANCE

Direct maintenance costs have been shown to contribute a large share of total aircraft operating costs. Reductions in maintenance labor and material costs, through improved reliability and simplified maintenance, should be emphasized in future R&D. Typical high cost systems, which should receive priority attention in these areas are:

- Navigation systems (e.g., Inertial Navigation Systems, INS)

- Auxiliary power units (poor reliability and high operating costs)

- Tire and brakes (high wear-out rate)

- Fault isolation and diagnosis (systems which aid in reducing the maintenance costs of other systems, but which themselves have high operating costs and/or low reliability)

- Routine maintenance tasks, including lubricated surfaces and lubricants

7.2 ADDITIONAL STUDY RECOMMENDATIONS

7.2.1 APPLICABILITY OF THE COST METHODOLOGY TO OTHER CONVENTIONAL AIRCRAFT TYPES

This study was based on conventional subsonic transport designs and operating experience. It was tested only on one new design—the TAC/Energy passenger transport airplane, which is a relatively modest departure from conventional airplanes.

It is recommended that the cost assessment methodology be exercised on other conventional types (e.g., pure freighters) and under other operating scenarios than those represented by American Airline's experience (e.g., extremely short and extremely long ranges), to determine its off design applicability, i.e., in areas not covered by the operating experience data base.

7.2.2 APPLICABILITY OF THE COST METHODOLOGY TO UNCONVENTIONAL AIRCRAFT TYPES

It is recommended that the methodology be exercised on unconventional transport designs to ascertain the methodology's applicability to a broad spectrum of transport airplane types. Modifications to the methodology should be made, as appropriate, to account for differences (or deficiencies) indicated for these other unconventional transport types. Examples are spanloaders, hydrogen-powered airplanes, and SSTs.

7.2.3 LANDING GEAR STUDIES

Landing gear systems have been shown to be a high cost item. However, relatively little is known about the effects of the operational environment (ambient temperature, thrust reverser usage, the effects of runway surface on tire wear, etc.) on the design and operating cost of landing gear, particularly in the area of tires and brakes. A detailed study of these effects is recommended.

7.2.4 AUXILIARY POWER SYSTEM STUDIES

Auxiliary power systems, principally APUs, contribute significant operating costs to transport airplanes so equipped. It is recommended that an indepth study of current design characteristics and operating procedures be made to determine their relationship to, and effect on, maintenance and ownership costs.

7.2.5 DRAG DETERIORATION STUDIES

Deterioration in engine fuel consumption and airplane drag during the life of the airplane contribute to high fuel costs. NASA has already established R&D programs that address the engine portion of this deterioration. It is recommended that equivalent effort be made on the airframe side to study the mechanics of drag deterioration. This should address the questions of how much and how fast drag buildup occurs, and how, at reasonable cost, to prevent it by improved design, to arrest it, and to restore the airframe all or part way to its factory new condition.

7.2.6 AIRCRAFT RELATED SUPPORT EQUIPMENT AND PERSONNEL TRAINING EXPENSES

A more in-depth study on the influence of aircraft technology on aircraft related support equipment and personnel training expenses (particularly flight crew and aircraft maintenance personnel) is recommended. Proposed hydrogen-powered aircraft may have a significant effect on aircraft introductory costs in these areas.

7.2.7 DELAYS AND CANCELLATIONS

Further work in establishing industry acceptable criteria for assessing the economic effects of schedule delays and cancellations is needed. An evaluation of the cost benefit relationship for eliminating delays, particularly for weather, appears to be worthwhile. This could lead to a study of routes on which the use of all weather landing systems are economically justifiable.

8.0 CONCLUSIONS

New methodologies for assessing subsonic commercial jet transport airframe direct maintenance costs to the ATA system level and aircraft related direct operating costs, for comparative purposes, have been developed.

The new methodologies are more predictive of the probable economic effects of incorporating advanced design and/or significant design changes than is currently available from either the 1967 ATA method or its derivatives.

In compliance with the statement of work, the influence of aircraft dispatch reliability on maintenance and operating costs was also explored and a model developed for predicting the frequency, number, and economic impact of schedule delays and cancellations for specific causes, and aircraft system, by aircraft type.

The study revealed that flight crew pay correlated well with the somewhat arbitrary chosen parameter of aircraft gross weight, although the present method of constructing flight crew pay includes factors for company seniority, aircraft cruise speed, and aircraft gross weight.

The study showed that small scale or gradual introduction of lighter (lower maximum landing weight) aircraft into a large fleet of conventional aircraft would result in temporary reductions in landing fees. The lighter of two new aircraft would be similarly benefitted. However, aircraft landing fees will neither permanently nor systematically be reduced as a result of aircraft weights being reduced through the use of lightweight materials such as composites. The landing fee rate will be adjusted upward by airport authorities to compensate for the loss in operating revenues brought about by a reduction in aircraft landing weight.

Landing gear, aircraft interiors, airborne auxiliary power units and routine inspection requirements constitute the major airframe maintenance labor and material expenditures.

APPENDIX I

AIRCRAFT SUPPORT EQUIPMENT AND FACILITY EXPENSES

The equipment and facilities necessary to support an aircraft in airline operation can be subdivided into the following:

Airport terminal facilities
Aircraft ground support and ramp equipment
Aircraft maintenance facilities
Aircraft maintenance tooling and equipment

Depending on the size of the airline operator and its management's policy regarding the degree of self sufficiency desired versus outside contracts, an equitable trade-off between the commitment of capital and a reduction of direct operating expense determines the size and location of investment in the above items. In addition, when introducing a new aircraft fleet, the size and location of any investment will be further influenced by the contemplated aircraft fleet size and its compatibility with existing aircraft in the fleet.

AIRPORT TERMINAL FACILITIES

Airport terminal facilities are designed to provide airlines the means to efficiently handle the departing passenger from either the terminal car park or curb side, through the ticketing and check-in process, out to the aircraft, and similar facilities at the passenger's destination provides services for passengers leaving the airport: this includes acquiring any checked baggage and proceeding to terminal curb side or car park with a minimum of delay and inconvenience.

The airport authority provides the basic building and facilities such as roads, car parks, etc. However, it is the responsibility of the airline to provide, either directly through ownership or lease from an aircraft/airport service organization, all aircraft passenger and baggage handling facilities in and around these terminals.

For the space occupied by an airline on an airport, rental charges are incurred. These charges vary from city to city and depend on the area and services provided. In addition, it is the responsibility of the airline to provide the equipment necessary to support the passenger and his needs in the airline designated airport area. In the general passenger areas, the provision and maintenance of any installed passenger related facilities are covered by the rentals paid by all user airlines serving that point.

Some of the equipment owned and installed by individual airlines in an airport terminal facility are as follows:

1. Ticket counters
2. Baggage scales
3. Reservation computer access equipment
4. Telephones and teletype machines
5. Flight information display boards and closed circuit TV equipment
6. Baggage handling equipment

7. Seating in the gate waiting area
8. Passenger address equipment
9. Flight crew and mechanic waiting and ready rooms
10. Flight dispatch and weather monitor information, radio, teletype and computer access equipment
11. Fixed and movable passenger loading ramps, etc.

The space an airline occupies in a terminal and investment in terminal facilities is a function of the size of the airline's operation at that point (the number of passengers handled, enplaned, and deplaned) during an optimum period and the number of flights to be serviced. The introduction of new aircraft which differ in size from those currently in service, or the need to support more aircraft at a given point can result in a substantial investment being required to meet the needs incurred by such changes.

Figures 118 and 119 provide an insight into the investment needed in airport terminal facilities both during an increase in fleet size and that associated with the introduction of larger aircraft, which require additional structure to cater for their needs in the form of new gate areas, passenger loading bridges, etc.

AIRCRAFT GROUND SUPPORT AND RAMP EQUIPMENT

To provide the means for moving aircraft to and from the terminal and hangar areas, support the needs for the servicing of the aircraft and provide facilities for moving the passenger, baggage and cargo between the terminal and the aircraft, a wide variety of ground support and ramp equipment is used.

This equipment, which consists of aircraft tow tractors, tow bars, air conditioning and electrical ground power units, baggage carts and tow tractors, passenger stands and equipment work stands, refueling trucks, etc. is either (1) owned by the airlines, (2) leased from an equipment company and operated by the airline, or (3) the service function contracted from an aircraft servicing company on an annual or a per departure basis.

For large airlines at major terminals the airlines may own or lease the equipment. However, at an out-station where the number of daily departures is small, the aircraft and passenger service function may either be contracted to another airline or an airline servicing company.

Again, the amount of capital investment in the aircraft ground support and ramp equipment is influenced by the aircraft fleet size, the number of operations, and the aircraft's compatibility with other owned or leased ground support and ramp equipment already in service at that point.

Again, figures 118 and 119 provide an awareness of the capital investment incurred by increasing fleet size or introducing new aircraft types which require aircraft ground support and ramp equipment significantly different from that which already exists.

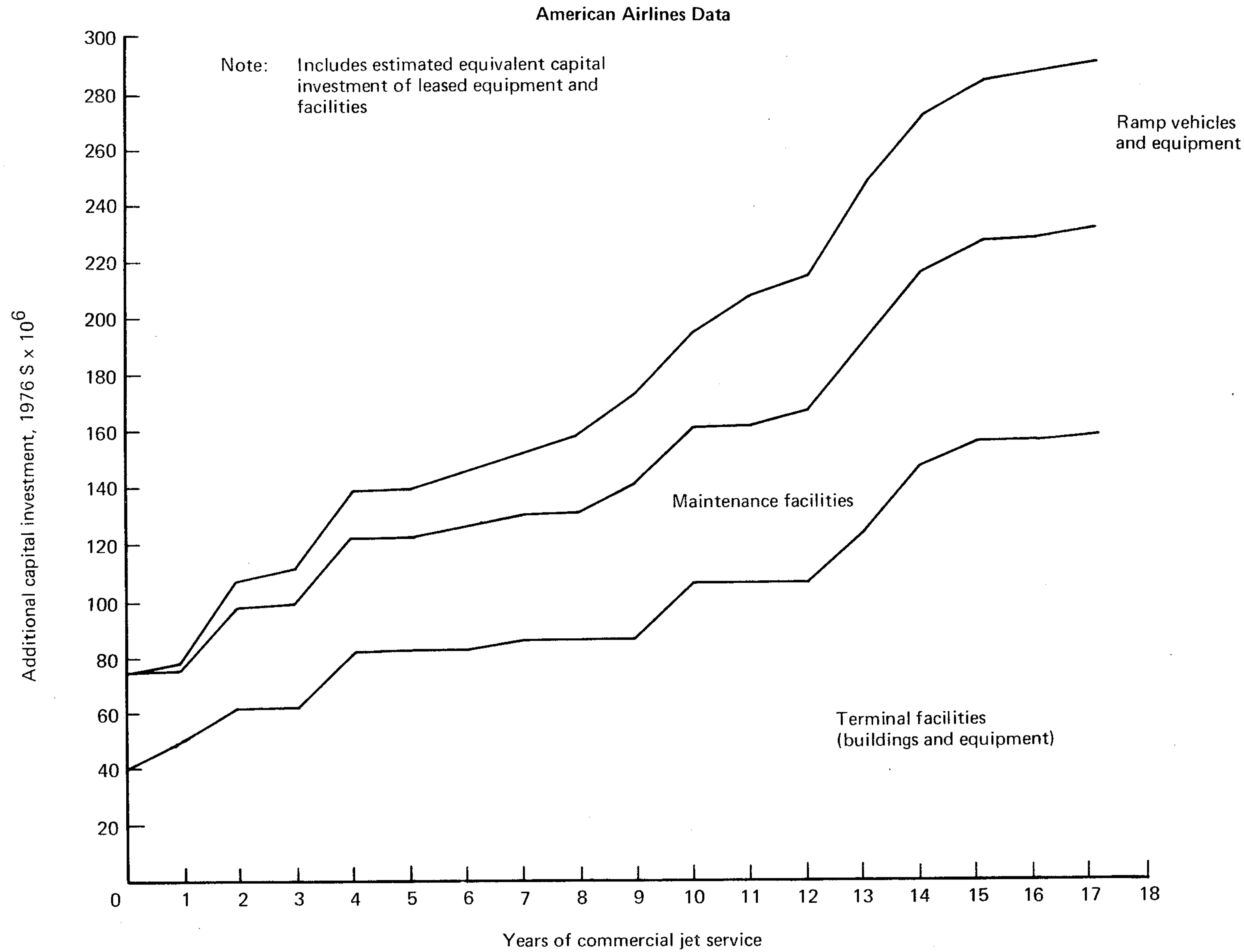

Figure 118.—Additional Capital Investment in Aircraft Related Support Equipment and Facilities (1976 $)

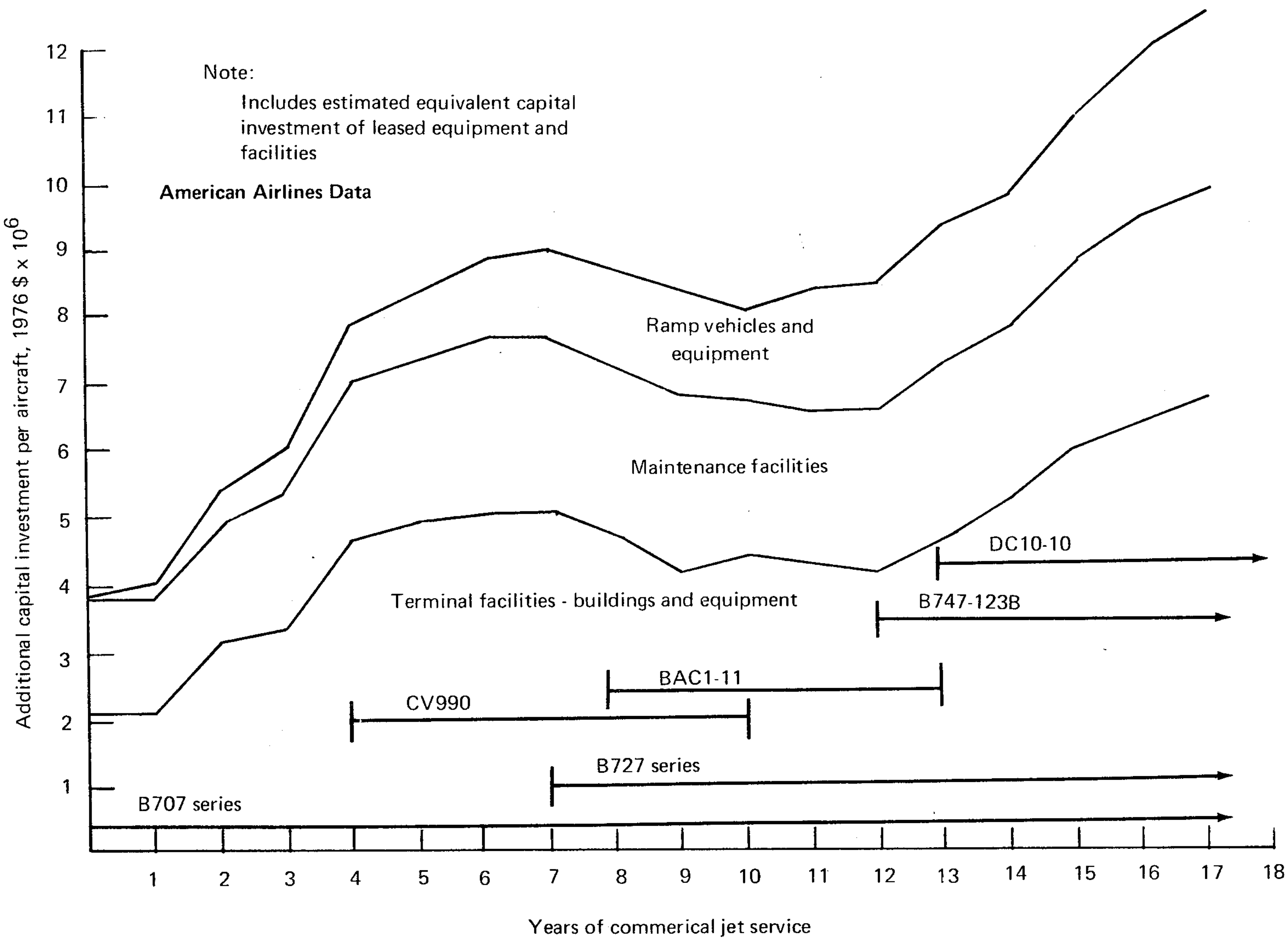

Figure 119.—Additional Capital Investment in Aircraft Related Support Equipment and Facilities (1976 $)

AIRCRAFT MAINTENANCE FACILITIES

Airlines must have access to maintenance facilities at various locations across their route network. Facilities are defined as the building type fixed installations which are not intended to be moved. They consist of such things as hangars, airplane maintenance work docks, shops, engine test cells, airplane parking aprons, engine runup noise suppressors, and jet blast deflectors. Facilities investments not only differ between the various line stations but additional differences exist between the line stations and the main maintenance base.

Facilities at line stations are determined principally by the total needs of the airplane at the station. Hangars, where provided, are sized to house the airplane component storage, changeout, and servicing. Even if a satellite shop with minor component repair and module exchange capability is needed, the additional facility cost impact is insignificant. Line station hangar investment is sensitive to the following factors:

1.	Route structure	Airplane overnight locations, climatic conditions, local acquisition costs.
2.	Airplane utilization	Time available for maintenance activity.
3.	Fleet size	Total system hangar floor space requirement, hangar size at major line maintenance bases.
4.	Maintenance program	Frequency/location of scheduled maintenance activity, division of activity between line stations and main base.
5.	Fleet composition	Size/configuration compatibility of the various airplanes.
6.	Pooling opportunity	Potential for leasing existing facilities for others.

Integrating these factors into an airline's individual situation could result in line maintenance hangar investments ranging from a few minimum capability units at $1 200 000 each to several $40 000 000 superbay hangars capable of housing four 747s plus two DC-10s.

Facilities investment at the main maintenance base of a major trunk airline can be in the 50 to 80 million dollar range. Hangar space for the total airplane must be provided and repair shops for airplane components and powerplants are also required. Here, the provision for component and powerplant repairs assume a large proportion of the total investments. Provisions must be made for housing such operations as plating, welding, heat-treating, assembly, and disassembly of large and heavy modules. They must also be made for cleaning and testing using explosive, toxic, flammable liquids, foundation stabilization, isolation of large machine tools and balancing machines and area protection for radioactive inspections. Also, special clean rooms may be required with adequate safeguards to ensure certain significant components being processed are not contaminated with foreign materials. Other facilities such as test cells for the aircraft engines and auxiliary power units will require special environmental safeguards to assure compliance with community regulations.

The magnitude of the investment is influenced not only by the size, type, and quantity of the aircraft in the fleet, but also by management's policy regarding the degree of self-sufficiency versus outside contracts. The latter is a tradeoff between commitment of capital and a reduction in operating expense.

Introduction of new aircraft, dimensionally and structurally similar to those existing, into a major trunk airline's fleet, would have a modest facilities investment cost impact, assuming that existing model airplanes would be replaced on a one-for-one basis. If retirement of the older airplanes were delayed, additional facilities could be required to accommodate the increased maintenance volume.

AIRCRAFT MAINTENANCE TOOLING/EQUIPMENT

Airline operation of an airplane requires that a wide array of tooling and equipment be provided. The size and composition of the existing fleet is significant. If the airline is operating an equivalent sized fleet of similar airplanes which will be phased out as the new fleet is phased in, a minimum additional investment will be required. If the new fleet is substantially different (i.e., 707 versus 747) or if the new airplanes are added to the existing ones, a high investment level may be necessary. Of the equipment needed, part can be regarded as general purpose; that is, applicable to all of the various airplane models in the operator's fleet. Other pieces of equipment are specialized and must be acquired to support the new airplane in spite of the existence of basically similar items supporting the current fleet.

In determining the applicability of general purpose equipment to the new fleet, the operator must consider size and quantity factors. If equipment is already available which is of sufficient size and strength to accommodate the new flight items, considerable expense can be avoided and the lead time shortened. If size and strength are adequate, there may still be a problem since the existing equipment may already be utilized to full capacity or there may be insufficient unused capacity to meet the new equipment's needs. This can be a challenging aspect of resources management since a big strain is imposed upon initial support capacity during the time interval when the new airplane is being phased in. If this situation is not managed well, the early operation of the new aircraft fleet will suffer from lack of adequate equipment support due to peaking of new problems. If, however, support equipment is provided on the basis of peak demand for the initial operation, there will be a large surplus when the new fleet has settled down into a routine operation.

Support tooling and equipment are usually capitalized since its useful life is longer than that of the flight equipment for which it was originally purchased.

Aircraft support is required in two principal categories:

1. That required for processing at the main maintenance shop (and at satellite maintenance shops if such are utilized) and,

2. That required for component transportation, storage, installation and removal.

Shop tooling/equipment can be classified as follows:

Main aircraft maintenance facilities

- Work stands (docks) to provide ready access to the aircraft wings, fuselage and empennage. These docks are usually self contained with numerous built-in access points for electrical power, air, water and lighting.
- Module intershop transport stands.
- Special hand and power tools.
- Special hoisting and handling tools.
- Parts storage racks.
- Flow and leak test rigs.
- Balancing machines and fixtures.
- Measuring and nondestructive test equipment.

Machine and processing shops

- General purpose machine tools and jigs/fixtures.
- Welding machines and jigs/fixtures.
- Plating equipment and fixtures.
- Heat treat equipment and fixtures.
- Special process equipment (such as: flame spray, vacuum furnaces, electrostatic discharge milling machines).

Component shops

- Avionic equipment work and test stands.
- Aircraft fuel, pneumatic and hydraulic system component test benches and adapters.
- Landing gear, wheel, tires, and brakes assembly and disassembly work stands.
- Valve and actuator flow and calibration stands and fixtures.
- Engine indicator system special tooling and calibration equipment.

- Aircraft seat, galley, bar repair facilities.

- Aircraft emergency equipment (life rafts, life jackets, slides, oxygen equipment, etc.) repair facilities.

The following equipment is also required for moving major items such as the powerplant, landing gear, air conditioning packs to the airplane, installation and removals, troubleshooting and servicing. (It should be noted that major component change capability is required at several stations throughout the route network since the time and place for changes cannot always be forecast accurately.)

Transport stands and shipping covers
Special installation removal tool kits and hoisting slings
Temporary holding fixtures for powerplants, modules, components, cowl panels, etc.
Power hoists
Aircraft jacking equipment
Diagnostic instruments, borescopes, x-ray and radio isotope equipment
Miscellaneous servicing tools

As outlined in the foregoing, there are too many variables to permit the development of a methodology that would predict aircraft support equipment and facility expense with any degree of accuracy.

APPENDIX II

TRAINING EXPENSE

With the introduction of each new aircraft type, a program of training for flight crews, flight attendants, airframe, engine and component mechanics and aircraft ground service and support personnel is required.

The extent of this training will chiefly depend on the differences in form, function, and technology, the new aircraft possesses, and those of current aircraft in the fleet.

Some measure of the financial impact of the introduction of a new aircraft type can be gained from the fact that during the introduction of wide bodied aircraft one airline incurred a one-time training expense in excess of $3 million for mechanic training on each aircraft type. In addition, annual expenditures in the order of $1 million are incurred providing initial and recurrent training to airframe engine and component mechanics and aircraft ground service and support personnel.

However, it is in the flight crew training area that the most significant impact (and expense) occurs, particularly if the new aircraft provides a major change in size, technology, performance, and cockpit layout.

Figure 120 outlines the distribution of additional capital investment in flight training facilities that have occurred in one airline since the introduction of domestic commercial jet service. Note the rapid build up of capital investment in facilities, simulators, and training aids once airlines and regulatory authorities recognized the value and savings in using cockpit procedural trainees and flight simulators for pilot training.

Figure 121 shows data from American Airlines of the number of aircraft flight hours that have been saved by the use of flight simulators to train flight crews over the last six years. To provide equivalent training flight time, a total of 11 additional aircraft (4, 707; 4, 727; 1, 747; and 2, DC-10s representing an investment in the order of $100 million) would have been required, plus the additional maintenance expense of these aircraft.

An additional factor, arising from the use of flight simulators in lieu of aircraft for the majority of flight training, is improved aircraft safety. Flight simulators also provide the opportunity to develop new cockpit procedures and flight profiles without increasing hazards and at a minimum cost.

The foregoing serves to provide an awareness of some of the potential costs brought about by the introduction of a new aircraft incorporating significant change whether advanced technology related or not.

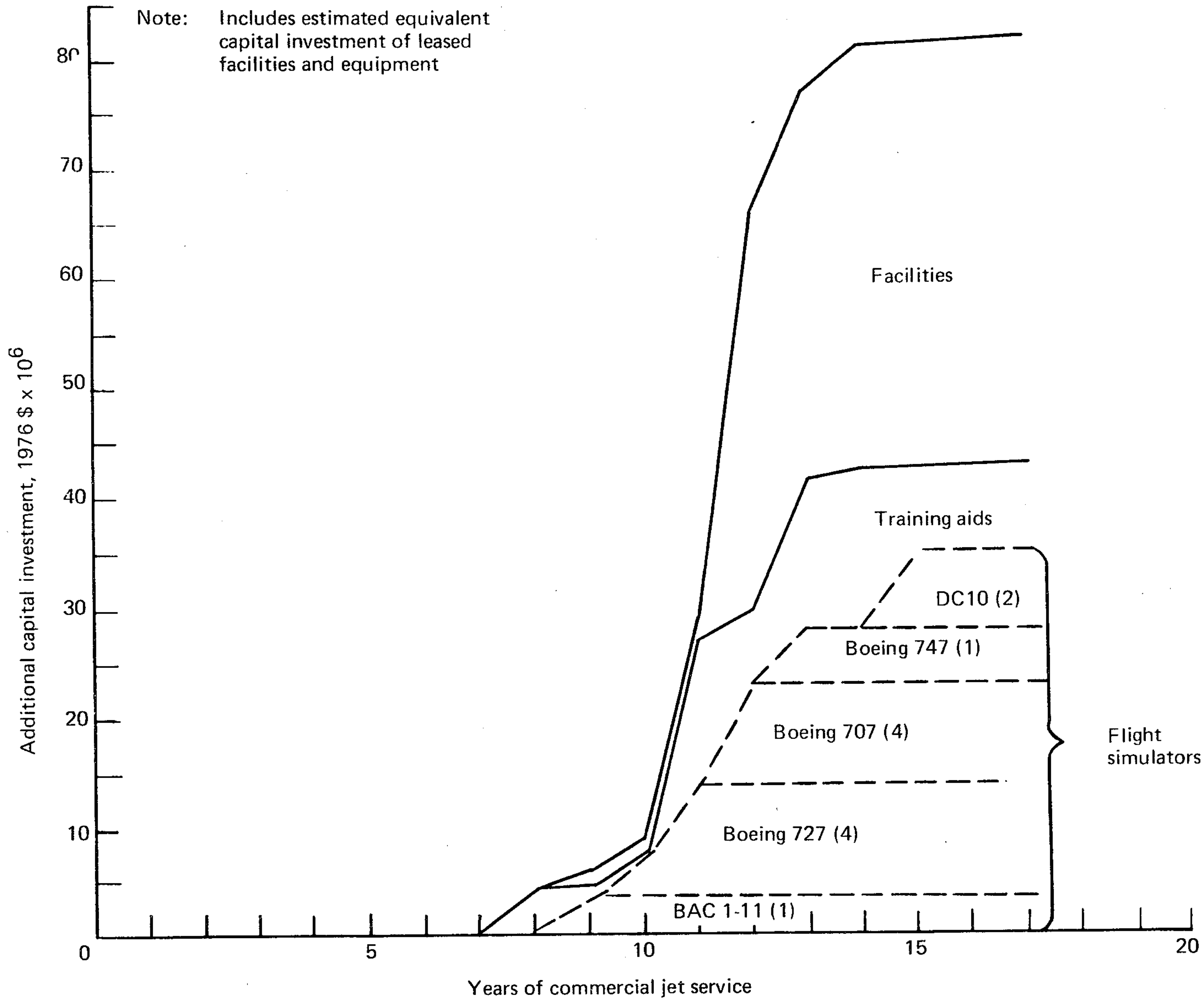

Figure 120.—Distribution of Additional Capital Investment In-Flight Training Facilities and Equipment (1976 $)

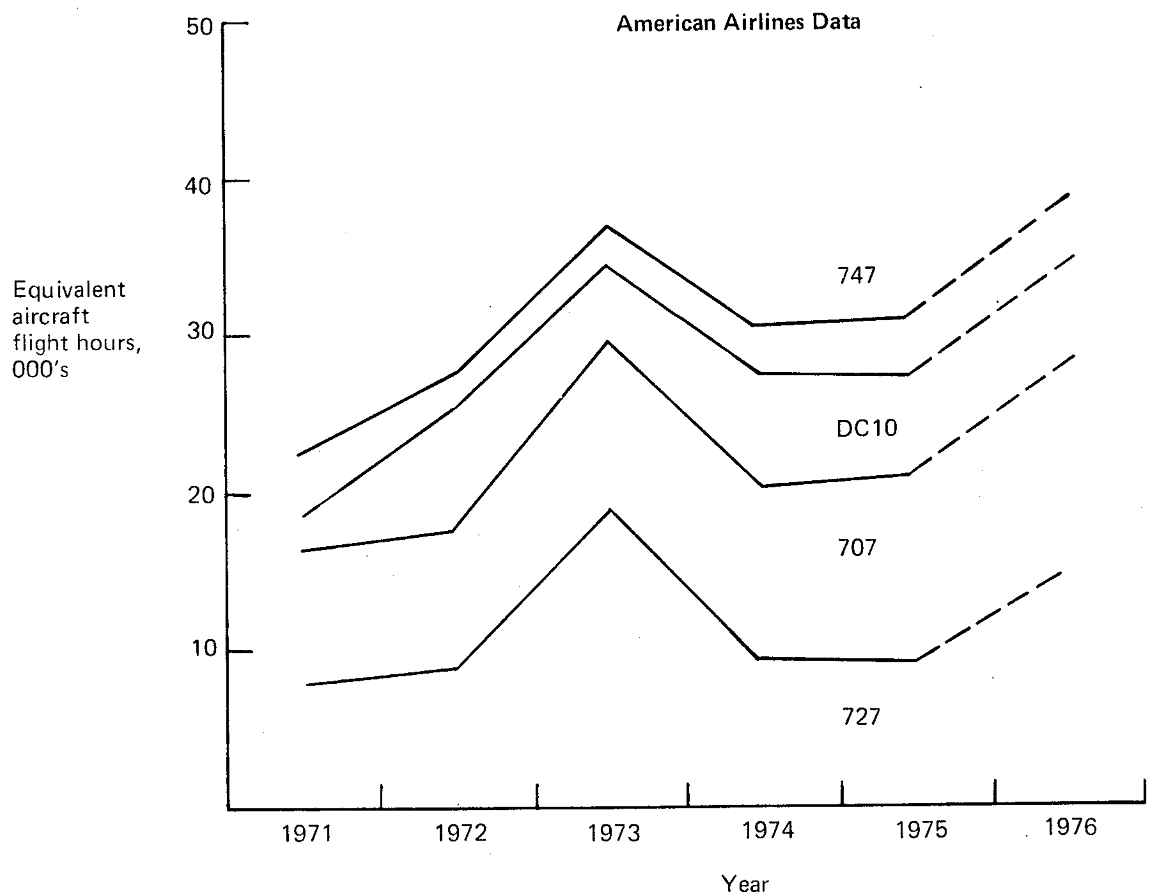

Figure 121.—Distribution of Aircraft Flight Hours Avoided by Simulator Use For Pilot Training

APPENDIX III

Section 11—Functional Classification—Operating Expenses of Group II and Group III Air Carriers

5100 Flying Operations.

(a) This function shall include expenses incurred directly in the in-flight operation of aircraft and expenses attaching to the holding of aircraft and aircraft operational personnel in readiness for assignment to an in-flight status.

(b) This function shall not include expenses incurred in repairing, servicing or storing aircraft, expenses incurred on the ground in protecting and controlling the in-flight movement of aircraft, or compensation of ground personnel and other expenses incurred in scheduling or preparing aircraft or aircraft operational personnel for flight assignment. Such expenses shall be included in function 5400 Maintenance, or function 6400 Aircraft and Traffic Servicing.

5400 Maintenance.

(a) This function shall include all expenses, both direct and indirect, incurred in the repair and upkeep of property and equipment as may be required to meet operating and safety standards; in inspecting or checking property and equipment in accordance with prescribed operational standards; and in polishing or cleaning property and equipment when such polishing or cleaning is not an incidental routine in connection with the normal productive use of property and equipment.

(b) This function shall include the cost of direct labor, materials, and outside services and maintenance overhead or other costs associated with maintenance operations regardless of the location at which incurred.

(c) This function shall not include costs incurred in the construction, improvement, or modification of property and equipment even when necessitated to meet new or changed operating or safety standards. Such costs shall be charged to appropriate property and equipment accounts.

(d) Costs incurred by aircraft handling personnel in visual inspection, minor check and servicing of aircraft, while in line service, shall not be included in this function when performed as an incidental routine during the normal productive use of aircraft but shall be included in function 6400 Aircraft and Tariff Servicing.

(e) Both Group II air carriers and Group III air carriers shall maintain the following subfunctions:

5200 *Direct Maintenance.*

a. This subfunction shall include the costs of labor, materials and outside services consumed directly in periodic maintenance operations and the maintenance and repair of property and equipment of all types and classes, regardless of the location at which incurred, exclusive of property and equipment carried in balance sheet accounts 1634 Maintenance and Engineering Equipment and 1640.1 Maintenance Buildings and Improvements, which shall be included in subfunction 5300 Maintenance Burden.

b. The cost of direct labor, materials and supplies, as well as outside repairs, used in the maintenance and repair of property and equipment shall be recorded on running job orders or tickets covering repairs and periodic inspections except servicing. Where a number of like items are maintained on a group basis, it will be necessary to maintain only one job order for each group.

c. When supervisory personnel such as crew chiefs, inspectors and foremen are engaged in direct labor in connection with equipment maintenance, a proportionate part of their salaries and wages shall be charged to the appropriate direct labor accounts. The cost of transporting property to and from shops for repair and maintenance shall be included as a part of the cost of the materials and supplies used in the repair or maintenance of such property and equipment. Transportation charges, customs and duties, etc., shall be included in the cost of repairs and maintenance operations when made by outside parties.

5300 *Maintenance Burden.*

a. This subfunction shall include all overhead or general expenses used directly in the activities involved in periodic maintenance operations and the maintenance and repair of property and equipment of all types and classes, including the cost of direct labor, materials and outside services used in the maintenance and repair of property and equipment carried in balance sheet accounts 1634 Maintenance and Engineering Equipment, and 1640.1 Maintenance Buildings and Improvements. It shall include expenses related to the administration of maintenance stocks and stores, the keeping of pertinent maintenance operations records, and the scheduling, controlling, planning and supervision of maintenance operations.

b. This subfunction shall not include expenses related to financial accounting, purchasing or other overhead activities which are of general applicability to all operating functions. Such expenses shall be included in function 6800 General and Administrative.

c. This subfunction shall include only those expenses attributable to the current air transport operations of the air carrier. Maintenance burden associated with capital projects of the air carrier, other than overhauls of airframes and aircraft engines, shall be allocated thereto in accordance with the provisions of section 2-9(b). Maintenance burden incurred in common with services to other companies and operating entities shall be allocated thereto on a pro rata basis unless such services are so infrequent in performance or small in volume as to result in no appreciable demands upon the air carrier's maintenance facilities. When overhauls of airframes or aircraft engines are as a consistent practice accounted for on an accrual basis instead of expensed directly, maintenance burden shall be allocated thereto on a pro rata basis. Standard burden rates may be employed for quarterly allocations of maintenance burden provided the rates are reviewed at the close of each fiscal year, at least. When the actual burden rate for the year differs materially from the standard burden rate applied, adjustment shall be made to reflect the actual costs incurred for the full accounting year. Allocations of maintenance burden to capital projects, and service sales to others shall be effected through the individual maintenance burden objective accounts, except that the air carrier may effect such allocations by credits to profit and loss account 77 Uncleared Expense Credits under circumstances in which the use of that account will not undermine the significance of the individual maintenance burden objective accounts in terms of the expense levels associated with the air carrier's air transport services. Maintenance burden allocated to overhauls shall be credited to profit and loss subaccounts 5372.2 or 5372.7 Airworthiness Reserve Charges. In accordance with the provisions of section 22(d) or 32(d), as applicable, each air carrier shall file with the Civil Aeronautics Board a statement in which procedures followed in allocating maintenance burden between current transport services, overhauls, capital projects and outside services are fully explained.

5500 Passenger Service.

This function shall include all expenses chargeable directly to activities contributing to the comfort, safety and convenience of passengers while in flight and when flights are interrupted. It shall not include expenses incurred in enplaning or deplaning passengers, or in securing and selling passenger transportation and caring for passengers prior to entering a flight status. Such expenses shall be included in functions 6400 Aircraft and Traffic Servicing and 6700 Promotion and Sales, respectively.

6400 Aircraft and Traffic Servicing.

(a) This function shall include the compensation of ground personnel and other expenses incurred on the ground incident to the protection and control of the in-flight movement of aircraft, scheduling and preparing aircraft operational crews for flight assignment, handling and servicing aircraft while in line operation, servicing and handling traffic on the ground, subsequent to the issuance of documents establishing the air carrier's responsibility to provide air transportation, and in-flight expenses of handling and protecting all nonpassenger traffic including passenger baggage.

(b) This function shall include only those aircraft servicing and cleaning expenses which are incurred as an incidental routine during the normal productive use of aircraft in line operations. It shall not include expenses incurred in the repair and maintenance of property and equipment, or in checking or inspecting property and equipment in accordance with prescribed operational standards when such activities are not an incidental routine during the normal productive use of aircraft. Such expenses shall be included in function 5400 Maintenance.

(c) This function shall not include expenses incurred in securing traffic, arranging aircraft space for traffic sold or in issuing documents confirming traffic sales and establishing the air carrier's responsibilities to provide air transportation. Such expenses shall be included in function 6700 Promotion and Sales. However, for purposes of this system of accounts, expenses attributable to the operation of airport traffic offices, excluding reservation centers, shall be included in this function. Expenses attributable to the operation of reservation or aircraft space control centers shall be included in function 6700 Promotion and Sales regardless of the location at which incurred.

(d) Group III air carriers shall further subdivide this function as follows:

6100 *Aircraft Servicing.*

a. This subfunction shall include the compensation of ground personnel and other expenses incurred on the ground incident to the protection and control of the in-flight movement of aircraft; scheduling or preparing aircraft operational crews for flight assignment; landing and parking aircraft;

visual inspection, routine checking, servicing and fueling of aircraft; and other expenses incurred on the ground incident to readying for arrival and take-off of aircraft.

6200 *Traffic Servicing.*

a. This subfunction shall include the compensation of ground personnel and other expenses incurred on the ground incident to handling traffic of all types and classes on the ground subsequent to the issuance of documents establishing the air carrier's responsibility to provide air transportation. Expenses attributable to the operation of airport traffic offices shall also be included in this subfunction; expenses attributable to reservations centers shall be excluded. It shall include expenses incurred in both enplaning and deplaning traffic as well as expenses incurred in preparation for enplanement and all expenses subsequent to deplanement.

b. This subfunction shall also include costs incurred in handling and protecting all nonpassenger traffic while in flight. It shall not include expenses incurred in contributing to the comfort, safety and convenience of passengers while in flight or when flights are interrupted. Such expenses shall be included in function 5500 Passenger Service.

6300 *Servicing Administration.*

a. This subfunction shall include expenses of a general nature incurred in performing supervisory or administrative activities relating solely and in common to subfunctions 6100 Aircraft Servicing and 6200 Traffic Servicing.

b. This subfunction shall not include supervisory or administrative expenses which can be charged directly to subfunction 6100 Aircraft Servicing or subfunction 6200 Traffic Servicing. Ncr shall this subfunction include expenses of a general administrative character and of significant amount regularly contributing to operating functions generally. Such expenses shall be included in function 6800 General and Administrative.

c. The expenses in this subfunction shall be recorded separately for each geographic location at which incurred.

6700 Promotion and sales.

(a) This function shall include expenses incurred in creating public preference for the air carrier and its services; stimulating the development of the air transport market; and promoting the air carrier or developing air transportation generally.

(b) It shall also include the compensation of personnel and other expenses incident to documenting sales; expenses incident to controlling and arranging or confirming aircraft space for traffic sold; expenses incurred in direct sales solicitation and selling of aircraft space; and expenses incurred in developing tariffs and schedules for publication.

(c) This function shall not include expenses incurred in handling traffic subsequent to the issuance of documents establishing the air carrier's responsibility to provide air transportation which shall be included in functions 5500 Passenger Service and 6400 Aircraft and Traffic Servicing. However, for purposes of this system of accounts, expenses attributable to the operation of airport traffic offices, excluding reservation centers, shall be included in function 6400 Aircraft and Traffic Servicing. Expenses attributable to the operation of reservation or aircraft space control centers shall be included in function 6700 Promotion and Sales regardless of the location at which incurred.

(d) Group III air carriers shall subdivide this function as follows:

6500 *Reservations and Sales.*

This subfunction shall include expenses incident to direct sales solicitation, documenting sales, controlling and arranging or confirming aircraft space sold, and in developing tariffs and schedules for publication. It shall also include expenses attributable to the operation of city traffic offices. Expenses incurred in stimulating traffic and promoting the air carrier or air transportation generally shall not be included in this subfunction but in subfunction 6600 Advertising and Publicity.

6600 *Advertising and Publicity.*

a. This subfunction shall include expenses incurred in creating public preference for the air carrier and its services; stimulating development of the air transport market; and promoting the air carrier or developing air transportation generally.

b This subfunction shall not include expenses incurred in direct sales solicitation and selling of aircraft space. Such costs shall be included in subfunction 6500 Reservations and Sales.

6800 General and Administrative.

(a) This function shall include expenses of a general corporate nature and expenses incurred in performing activities which contribute to more than a single operating function such as general financial accounting activities, purchasing activities, representation at law, and other general operational administration, which are not directly applicable to a particular function.

(b) This function shall not include expenses incurred directly in promoting traffic or in promoting relations of the air carrier generally with the public which shall be included in function 6700 Promotion and Sales. Nor shall this function include expenses, regularly applicable in large part to a specific function, which contribute only incidentally, or in small amount, to various other functions. Such expenses when of such size as will not distort the function to which predominantly related, shall be included in the specific function to which regularly related. However, expenses of a general administrative character and of significant amount regularly contributing to operating functions generally shall be included in this function.

7000 Depreciation and Amortization.

This function shall include all charges to expense to record losses suffered through current exhaustion of the serviceability of property and equipment due to wear and tear from use and the action of time and the elements, which are not replaced by current repairs, as well as losses in serviceability occasioned by obsolescence, supersession, discoveries, change in popular demand or action by public authority. It shall also include charges for the amortization of capitalized developmental and preoperating costs, and other intangible assets applicable to the performance of air transportation. (See section 5-5 and sections 6—1830 and 1880.)

7100 Transport-related expenses.

(a) This function shall include all expense items applicable to the generation of transport-related revenues included in section 9, Function 4800.

(b) Such expense related to services of a magnitude or scope beyond an incidental adjunct to air transportation services shall not be included in this function (see section 1-6(b)). Expenses applicable to the generation of such revenues shall be included in profit and loss classification 8100, Nonoperating Income and Expense-Net, and the accounting modified to conform with that of a nontransport division whether or not the service is organized as a nontransport division.

(c) This function shall also include expenses representing increases in costs incurred in common with the air transport service, to the extent such increases result from the added transport-related services, as well as a pro rata share of the costs incurred by the air carrier in operating facilities which are used jointly with others. As a general rule, this function shall not include those expenses, other than joint facilities costs, which would remain as an essential part of the air transport services if the transport-related services were terminated.

(d) In accordance with the provisions of sections 22(d) and 32(d), as applicable, each air carrier shall file with the Civil Aeronautics Board a statement of accounting procedures setting forth methods used in assigning or prorating expenses between transport-related services and transport operations.

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TRANSPORT EXPENSES

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21 **General Management Personnel.**

Record here the compensation, including vacation and sick leave pay, of general officers and supervisors, and immediate assistants regardless of locality at which based, responsible for an activity not provided for in profit and loss accounts 25 through 35, inclusive, or an activity involving two or more such accounts.

23 **Pilots and Copilots.**

Record here the compensation, including vacation and sick leave pay, of pilots and copilots assigned or held inactive awaiting assignment to flight duty.

24 **Other Flight Personnel.**

Record here the compensation, including vacation and sick leave pay, of other flight personnel assigned or held inactive awaiting assignment to flight status, not responsible for the in-flight management of aircraft, such as engineers, navigation officers and cabin attendants.

25 **Maintenance Labor.**

(a) Record here the compensation for time of personnel spent directly on specific property and equipment maintenance projects. (See sections 10 and 11-5200.) Vacation and sick leave pay shall be charged to profit and loss account 28 Trainees, Instructors and Unallocated Shop Labor.

(b) This account shall be subdivided as follows:

GROUP II AND GROUP III AIR CARRIERS

25.1 *Labor—Airframes.*

Record here the direct labor expended upon airframes and spare parts related to airframes.

25.2 *Labor—Aircraft Engines.*

Record here the direct labor expended upon aircraft engines and spare parts related to aircraft engines.

25.3 *Labor—Other Flight Equipment.*

Record here the direct labor expended upon flight equipment (including instruments) other than airframes, aircraft engines and spare parts related to airframes and aircraft engines. Instruments shall include all gauges, meters, measuring devices, and indicators, together with appurtenances thereto for installation in aircraft and aircraft engines which are maintained separately from airframes and aircraft engines.

GROUP I AIR CARRIERS

25.6 *Labor—Flight Equipment.*

Record here the direct labor expended upon flight equipment of all types and classes.

ALL AIR CARRIER GROUPS

25.9 *Labor—Ground Property and Equipment.*

Record here the direct labor expended upon ground property and equipment of all types and classes. Direct labor expended upon general ground properties shall be charged to subfunction 5200 Direct Maintenance; and direct labor expended upon maintenance buildings and equipment shall be charged to subfunction 5300 Maintenance Burden.

26 Aircraft and Traffic Handling Personnel.

(a) Record here the compensation, including vacation and sick leave pay, of personnel of all types and classes, including direct supervisory personnel, assigned to ground activities, engaged directly in protecting and controlling aircraft in flight, scheduling and preparing flight crews for flight assignment, parking and servicing aircraft incidental to line operations, and of personnel of all types and classes engaged in servicing and handling traffic of all types and classes on the ground.

(b) This account shall be subdivided as follows by Group II and Group III air carriers:

26.1 *General Aircraft and Traffic Handling Personnel.*

Record here compensation of personnel handling or controlling aircraft and generally servicing or handling traffic of all types and classes whose activities are not identifiable with the particular activities provided for in subaccounts 26.2, 26.3 or 26.4, inclusive.

26.2 *Aircraft Control Personnel.*

Record here compensation of personnel whose activities are identifiable with the protection and control of aircraft in flight and in scheduling or preparing flight crews for flight assignment.

26.3 *Passenger Handling Personnel.*

Record here compensation of personnel whose activities are identifiable with the handling of passengers.

26.4 *Cargo Handling Personnel.*

Record here compensation of personnel whose activities are identifiable with the Handling of passenger baggage, mail, express or freight.

28 Trainees, Instructors, and Unallocated Shop Labor.

(a) Record here the compensation, including vacation and sick leave pay, of instructors and personnel in an off-the-job training status; direct maintenance personnel compensation not assigned to specific projects; and vacation or sick leave pay of direct maintenance personnel.

(b) This account shall be subdivided as follows by all air carrier groups:

28.1 *Trainees and Instructors.*

Record here the compensation of instructors and personnel in a training status.

28.2 *Unallocated Shop Labor.*

Record here the pay of direct maintenance personnel which has not been assigned to profit and loss account 25 Maintenance Labor for time spent on specific maintenance projects, and vacation or sick leave pay of direct maintenance personnel.

30 Communications Personnel.

Record here the compensation, including vacation and sick leave pay, of personnel of all types and classes, including direct supervisory personnel, engaged in local, interstation, or ground-air communication activities This account shall include compensation of personnel such as radio operators, telephone operators, switchboard operators, teletype operators, messengers, etc.

31 Record Keeping and Statistical Personnel.

Record here the compensation, including vacation and sick leave pay, of personnel including supervisory personnel, whose primary duties relate to maintaining records or conducting economic or other analyses required for general management controls, such as accountants, economists, statisticians, maintenance record clerks, stores record clerks, stores receiving and issuing clerks and file clerks. The account shall not include personnel engaged in documentation or other activities constituting an integral part of activities encompassed by other objective accounts.

32 Lawyers and Law Clerks.

Record here the compensation, including vacation and sick leave pay, of air carrier personnel engaged in law research or representing the air carrier in matters of law.

33 Traffic Solicitors.

Record here the compensation, including vacation and sick leave pay, of personnel engaged directly in solicitation of traffic of all types and classes. This account shall not include compensation of traffic office personnel engaged in soliciting activities incidental to the documenting of sales and assigning aircraft space which shall be included in profit and loss account 26 Aircraft and Traffic Handling Personnel.

34 Purchasing Personnel.

(a) Record here the compensation, including vacation and sick leave pay, of personnel, including direct supervisory personnel, engaged in purchasing activities.

(b) This account shall include compensation of personnel engaged in maintaining purchasing records but shall not include compensation of personnel responsible for the control of inventories or stores which shall be included in objective account 31 Record Keeping and Statistical Personnel. In cases where the responsibility for maintaining purchasing and stores records are inseparable, the related compensation may be accounted for in accordance with dominant responsibilities.

35 Other Personnel.

Record here the compensation, including vacation and sick leave pay, of personnel whose activities are not identifiable with activities provided for in profit and loss accounts 21 through 34, inclusive.

36 Personnel Expenses.

(a) Record here expenses incurred by officers, executives, directors and other personnel, whether for the benefit of the air carrier or for the private benefit of such persons, which are directly or indirectly borne by the air carrier.

(b) This account shall include allowances in lieu of expenses as well as expenses incurred for travel, lodgings, meals, entertainment of individuals or groups of individuals, and membership fees and dues in professional or social clubs and associations.

(c) Records shall be maintained in a conveniently accessible form which will separately and clearly document each charge to this account in terms of its natural characteristics and contribution to the performance of the air carrier's transport operations. The records shall be maintained in such manner as will identify specifically the persons incurring the cost. Costs for standby hotel or other facilities maintained for the air carrier's personnel generally need not be allocated among the individuals using such facilities; however, sufficiently detailed records are required to identify the use made of such facilities by each individual.

(ER-948, 1-1-76)

37 Communications Purchased.

Record here expenses, including related taxes, incurred for rental of communication services and for communication services of all types and classes not provided by personnel of the air carrier, such as telegraph, telephone, teletype, private line services, and charges for communication services from organizations operated jointly with associated companies or others.

38 Light, Heat, Power and Water.

Record here charges related to the provision of light, heat, power and water, including related taxes.

39 Traffic Commissions.

(a) Record here charges by others, including associated companies, for commissions arising from sales of transportation. Commissions, fees or other charges incurred for general agency services, as opposed to commissions arising from sales of transportation, shall not be included in this account but in profit and loss account 42 General Services Purchased—Associated Companies or profit and loss account 43 General Services Purchased—Outside, as appropriate.

(b) This account shall be subdivided as follows by Group II and Group III air carriers:

39.1 *Commissions—Passenger.*

Record here charges for commissions arising from sales of passenger transportation.

39.2 *Commissions—Property.*

Record here charges for commissions arising from sales of nonpassenger transportation.

40 Legal Fees and Expenses.

Record here expenditures incurred for legal services by counsel retained on a fee basis and related expenses reimbursed or borne directly by the air carrier and other expenses incurred directly by the air carrier for legal supplies not obtainable from the air carrier's general stationery stock. This account shall not be charged with legal fees or expenses incurred in connection with claims occasioned by accidents or other casualties. Such charges shall be accumulated in balance sheet account 1890 Other Deferred Charges and cleared to profit and loss account 58 Injuries, Loss and Damage upon settlement of insurance claims. Nor should this account include fees or expenses related to developmental projects. Such expenses shall be included as appropriate in profit and loss account 89 Miscellaneous Nonoperating Debits or balance sheet account 1830 Developmental and Preoperating Costs.

41 Professional and Technical Fees and Expenses.

Record here fees and expenses, other than legal fees and expenses, incurred for outside professional and technical services which are reimbursed or borne directly by the air carrier. This account shall not include fees or expenses related to developmental projects. Such expenses shall be included, as appropriate, in profit and loss account 89 Miscellaneous Nonoperating Debits or balance sheet account 1830 Developmental and Preoperating Costs.

42 General Services Purchased—Associated Companies.

(a) Record here charges for services performed for the air carrier by associated companies which are not identifiable with services provided for in profit and loss accounts 37 through 41, inclusive, or which are not expressly indentifiable with other objective expense accounts.

(b) Charges from associated companies for services provided the air carrier under aircraft interchange agreements or other agreements embracing a complete activity or service such as the operation of jointly used ground facilities, shall be included in this account for each operating function to which the services contribute. Charges for providing aircraft capacity including charges for depreciation and interest on the capital related to the flight equipment provided shall be included in function 5100 Flying Operations.

(c) This account shall be subdivided as follows by each air carrier group:

GROUP II AND GROUP III AIR CARRIERS

42.1 *Airframe Repairs—Associated Companies.*

Record here charges by associated companies for maintenance or repair of airframes and spare parts related to airframes owned or leased by the air carrier. Charges by associated companies for maintenance of airframes provided under aircraft interchange agreements shall not be included in this subaccount but in subaccount 42.7 Aircraft Interchange Charges—Associated Companies.

42.2 *Aircraft Engine Repairs—Associated Companies.*

Record here charges by associated companies for maintenance or repair of aircraft engines including spare parts related to aircraft engines owned or leased by the air carrier. Charges by associated companies for maintenance of aircraft engines provided under aircraft interchange agreements shall not be included in this subaccount but in subaccount 42.7 Aircraft Interchange Charges—Associated Companies.

42.3 *Other Flight Equipment Repairs—Associated Companies.*

Record here charges by associated companies for maintenance or repair of flight equipment (including instruments) owned or leased by the air carrier, other than airframes, aircraft engines, and spare parts related to airframes and aircraft engines. Instruments shall include all gauges, meters, measuring devices, and indicators, together with appurtenances thereto for installation in aircraft and aircraft engines, which are maintained separately from airframes and aircraft engines. Charges by associated companies for maintenance of flight equipment provided under aircraft interchange agreements shall not be included in this subaccount but in subaccount 42.7 Aircraft Interchange Charges—Associated Companies.

GROUP I AIR CARRIERS

42.6 *Flight Equipment Repairs—Associated Companies.*

Record here charges by associated companies for maintenance or repair of flight equipment of all types and classes owned or leased by the air carrier. Charges by associated companies for maintenance of flight equipment provided under aircraft interchange agreements shall not be included in this subaccount but in subaccount 42.7 Aircraft Interchange Charges—Associated Companies.

ALL AIR CARRIER GROUPS

42.7 *Aircraft Interchange Charges—Associated Companies.*

Record here charges by associated companies for providing aircraft capacity or services related to the direct operation or maintenance of flight equipment under aircraft interchange agreements.

42.8 *General Interchange Service Charges—Associated Companies.*

Record here charges by associated companies for services provided the air carrier under aircraft interchange agreements, other than charges related to the direct operation or maintenance of flight equipment, including all charges for maintenance and repair of ground properties, as well as fees or charges for traffic solicitation and sales.

or supervision and administration covered by the aircraft interchange agreements. Charges for depreciation or interest on capital related to flight equipment provided under interchange agreements shall not be included in this subaccount but in subaccount 42.7 Aircraft Interchange Charges-Associated Companies.

42.9 *Other Services—Associated Companies.*

a. Record here charges for services performed by associated companies not provided for elsewhere.

b. This subaccount shall include only those charges for services, not provided for in profit and loss accounts 37 to 41, inclusive, and subaccounts 42.1 to 42.8, inclusive, embracing a complete activity or service provided by associated companies, such as the operation of traffic offices or other facilities used jointly with the air carrier, which do not represent reimbursement of specific expense elements incurred expressly for the benefit of the air carrier. Reimbursement of expenses incurred expressly for the benefit of the air carrier shall be entered in appropriate personnel compensation or other objective expense accounts. The cost of services received in the repair of general ground properties shall be charged to subfunction 5200 Direct Maintenance; and services received in the repair of maintenance buildings and equipment shall be charged to subfunction 5300 Maintenance Burden.

43 General Services Purchased—Outside.

(a) Record here charges for services performed for the air carrier by other than associated companies which are not identifiable with services provided for in profit and loss accounts 37 through 41, inclusive, or which are not expressly identified with other objective expense accounts.

(b) Charges from others for services provided the air carrier under aircraft interchange agreements or other agreements embracing a complete activity or service, such as the operating of jointly used ground facilities, shall be included in this account for each operating function to which the services contribute. Charges for providing aircraft capacity, including charges for depreciation and interest on the capital related to the flight equipment provided, shall be included in function 5100 Flying Operations.

(c) This account shall be subdivided by each air carrier group, as follows:

GROUP II AND GROUP III AIR CARRIERS

43.1 *Airframe Repairs—Outside.*

Record here charges for maintenance or repair of airframes and spare parts related to airframes owned or leased by the air carrier. Charges by others for maintenance of airframes provided under aircraft interchange agreements shall not be included in this subaccount but in subaccount 43.7 Aircraft Interchange Charges—Outside.

43.2 *Aircraft Engine Repairs—Outside.*

Record here charges for maintenance or repair of aircraft engines, including spare parts related to aircraft engines owned or leased by the air carrier. Charges by others for maintenance of aircraft engines provided under aircraft interchange agreements shall not be included in this subaccount but in subaccount 43.7 Aircraft Interchange Charges—Outside.

43.3 *Other Flight Equipment Repairs—Outside.*

Record here charges for maintenance or repair of flight equipment (including instruments) owned or leased by the air carrier, other than airframes, aircraft engines, and spare parts related to airframes and aircraft engines. Instruments shall include all gauges, meters, measuring devices, and indicators, together with appurtenances thereto for installation in aircraft and aircraft engines, which are maintained separately from airframes and aircraft engines. Charges by others for maintenance of flight equipment provided under aircraft interchange agreements shall not be included in this subaccount but in subaccount 43.7 Aircraft Interchange Charges—Outside.

GROUP I AIR CARRIERS

43.6 *Flight Equipment Repairs—Outside.*

Record here charges for maintenance or repair of flight equipment of all types and classes owned or leased by the air carrier. Charges by others for maintenance of flight equipment provided under aircraft interchange agreements shall not be included in this subaccount but in subaccount 43.7 Aircraft Interchange Charges—Outside.

ALL AIR CARRIER GROUPS

43.7 *Aircraft Interchange Charges—Outside.*

Record here charges by other than associated companies for providing aircraft capacity or services related to the direct operation or maintenance of flight equipment under aircraft interchange agreements.

43.8 *General Interchange Service Charges—Outside.*

Record here charges by others, except associated companies, for services provided the air carrier under aircraft interchange agreements, other than charges related to the direct operation or maintenance of flight equipment, including all charges for maintenance and repair of ground properties, as well as fees or charges for traffic solicitation and sales, or supervision and administration covered by the aircraft interchange agreements. Charges for depreciation or interest on capital related to flight equipment provided under interchange agreements shall not be included in this subaccount but in subaccount 43.7 Aircraft Interchange Charges—Outside.

43.9 *Other Services—Outside.*

Record here charges for maintenance and repair of ground property and equipment of all types and classes and other charges for services performed by others not provided for elsewhere. This subaccount shall include only those charges for services not provided for elsewhere in profit and loss accounts 37 to 43 embracing a complete activity or service provided by other than associated companies such as the operation of traffic offices or other facilities used jointly with the air carrier which do not represent reimbursement of specific expense elements incurred expressly for the benefit of the air carrier. Reimbursement of expenses incurred expressly for the benefit of the air carrier shall be entered in appropriate personnel compensation or other objective expense accounts. The cost of services received in the repair of general ground properties shall be charged to subfunction 5200 Direct Maintenance; and services received in the repair of maintenance buildings and equipment shall be charged to subfunction 5300 Maintenance Burden.

44 Landing Fees.

Record here the charges and fees incurred for landing of aircraft while in line operation.

45 Aircraft Fuels and Oils.

(a) Record here the cost of fuels and oils issued from stocks of the air carrier, or delivered directly by others, to aircraft for use in flight operations. Adjustments of inventories of aircraft fuel and oil shall also be entered in this account The cost of fuels and oils used in repairs and maintenance services and nonrefundable fuel and oil taxes shall not be included in this account but in profit and loss accounts 49 Shop and Servicing Supplies and 69 Taxes—Other than Payroll, respectively.

(b) This account shall be subdivided as follows by Group II and Group III air carriers:

45.1 *Aircraft Fuels.*

Record here the cost of fuels used in flight operations.

45.2 *Aircraft Oils.*

Record here the cost of oils used in flight operations.

46 Maintenance Materials.

(a) Record here the cost of materials and supplies consumed directly in specific property and equipment maintenance projects.

(b) This account shall be subdivided as follows:

GROUP II AND GROUP III AIR CARRIERS

46.1 *Materials—Airframes.*

Record here the cost of materials and supplies consumed directly in maintenance of airframes and spare parts related to airframes.

46.2 *Materials—Aircraft Engines.*

Record here the cost of materials and supplies consumed directly in maintenance of aircraft engines and spare parts related to aircraft engines.

46.3 *Materials—Other Flight Equipment.*

Record here the cost of materials and supplies consumed directly in maintenance of flight equipment (including instruments) other than airframes and aircraft engines, or spare parts related to airframes and aircraft engines. Instruments shall include all gauges, meters, measuring devices, and indicators, together with appurtenances thereto for installation in aircraft and aircraft engines, which are maintained separately from airframes and aircraft engines.

GROUP I AIR CARRIERS

46.6 *Materials—Flight Equipment.*

Record here the cost of materials and supplies consumed directly in the maintenance of flight equipment of all types and classes

ALL AIR CARRIER GROUPS

46.9 *Materials—Ground Property and Equipment.*

Record here the cost of materials and supplies consumed directly in the maintenance of ground property and equipment of all types and classes. The cost of materials and supplies consumed in the repair of general ground properties shall be charged to subfunction 5200 Direct Maintenance and materials and supplies consumed in the repair of maintenance buildings and equipment shall be charged to subfunction 5300 Maintenance Burden.

47 Rentals.

Record here rentals, fees, or charges incurred in the use of property and equipment provided by others. When a lease arrangement provides that the amounts paid include charges for maintenance, insurance, or taxes, the amounts related thereto shall not be recorded in this account but in the appropriate expense account to which related.

49 Shop and Servicing Supplies.

Record here the cost of supplies and expendable small tools and equipment used in maintaining, servicing and cleaning property or equipment the cost of which cannot be directly assigned to a specific job or type of work.

50 Stationery, Printing and Office Supplies.

Record here the cost of stationery and forms used by the air carrier including the cost of engineering and shipping supplies.

51 Passenger Food Expense.

(a) Record here the cost of food and refreshments served passengers except food costs arising from interrupted trips.

(b) If the air carrier prepares its own food, the initial cost and expenses incurred in the preparation thereof shall be accumulated in a clearly identified clearing account through which the cost of food shall be cleared to this account, to profit and loss account 36, Personnel Expenses, and to profit and loss account 10, Restaurant and Food Service (Ground), on bases which appropriately allocate the cost of food served passengers, the cost of food provided employees without charge and the cost of food sold.

53 Other Supplies.

Record here the cost of supplies consumed and not provided for otherwise.

54 Inventory Adjustments.

Record here adjustments for overage, shortage or shrinkage of inventories carried in balance sheet accounts 1310 Flight Equipment Expendable Parts and 1330 Miscellaneous Materials and Supplies. Adjustment of aircraft fuel and oil inventories shall not be included in this account but in profit and loss account 45 Aircraft Fuels and Oils. Gains or losses from retirements of materials and supplies shall not be recorded in this account but in profit and loss account 81 Capital Gains and Losses.

55 Insurance-General.

Record here the cost of public liability and property damage insurance and all other general insurance except insurance covering liability for injuries, loss, and damage to passengers and cargo, and insurance carried for the protection or welfare of employees.

56 Insurance—Traffic Liability.

Record here the cost of purchased insurance and provisions for self-insurance covering liability for injuries, loss and damage to passengers and cargo.

57 Employee Benefits and Pensions.

(a) Record here all costs for the benefit or protection of employees including all pension expenses whether for payments to or on behalf of retired employees or for accruals or annuity payments to provide for pensions; and all expenses for accident, sickness, hospital, and death benefits to employees or the cost of insurance or provisions for self-insurance to provide these benefits. Include, also, expenses incurred in medical, educational, or recreational activities for the benefit of employees. Do not include vacation and sick leave pay, or salaries of doctors, nurses, trainees, or instructors, which shall be recorded in the regular salary accounts.

(b) Each air carrier which records pension benefit expenses in the account required by paragraph (a) of this section, is required to file a standard statement of accounting procedures and, in addition, a copy of Department of Labor Form D-2, Employee Welfare or Pension Benefit Plan Annual Report Form as prescribed by section 2-19.

58 Injuries, Loss and Damage.

Record here the remainder of gains, losses or costs resulting from accidents, casualties or mishandlings, after offsetting insurance recoveries, as accumulated until finally determined, in balance sheet account 1890 Other Deferred Charges. This account shall not include gains or losses from retirement of property and equipment resulting from casualties. Such gains or losses shall be recorded in appropriate capital gains or losses accounts.

59 Tariffs, Schedules and Timetables.

Record here the production and distribution cost, excluding compensation of air carrier personnel, of all tariffs, operating schedules, timetables, circulars and related quick reference charts.

60 Advertising.

Record here the cost, excluding compensation of air carrier personnel, of all space, direct mail, spot and other advertising for the purpose of increasing air travel, disseminating air travel information and publicizing services offered by the air carrier.

62 Other Promotional and Publicity Expenses.

Record here the costs, excluding compensation of air carrier personnel, of producing and distributing publicity releases and other expenses, not chargeable to profit and loss accounts 59 and 60, incurred for the purpose of publicizing or improving the public relations of the air carrier generally.

63 Interrupted Trips Expense.

Record here expenses allowed or paid for the care and serving of passengers because of unscheduled interruptions in passenger journeys. Transportation refunds and the cost of forwarding traffic by surface common carrier or otherwise as a result of such interruptions shall not be charged to this account but to the appropriate operating revenue account.

64 Memberships.

Record here the cost of membership dues in trade associations, chambers of commerce, or other business associations and organizations together with special assessments related thereto.

65 Corporate and Fiscal Expenses.

Record here corporate and fiscal fees and expenses of the air carrier and all expenses in connection with exchange and transfer of capital stock excluding expenses in connection with original issuance of capital stock.

66 Uncollectible Accounts.

Record here losses from uncollectible accounts and reserve provisions and adjustments thereto, for such losses. When reserves for uncollectible accounts are established, losses as realized shall be charged against such reserves and shall not be charged to this account.

67 Clearance, Customs and Duties.

Record here clearance, customs, duties and brokerage fees and charges applicable to clearing aircraft and traffic.

68 Taxes—Payroll.

Record here all taxes levied against the air carrier based upon or directly relating to compensation of personnel.

69 Taxes—Other Than Payroll.

(a) Record here all taxes levied against the air carrier not otherwise provided for including nonrefundable aircraft fuel and oil taxes. Interest and penalties on delinquent taxes shall not be charged to this account but to profit and loss accounts 87 Interest Expense and 89 Miscellaneous Nonoperating Debits, respectively.

(b) Entries to this account shall clearly reveal each kind of tax and the governmental agency to which paid or payable.

71 Other Expenses.

Record here all expenses ordinarily associated with air transportation and its incidental services not provided for otherwise.

72 Aircraft Overhauls.

(a) Record here airframe and aircraft engine overhauls of the current period which are transferred to balance sheet subaccounts 1601.2 Unamortized Airframe Overhauls or 1602.2 Unamortized Aircraft Engine Overhauls. This account shall also include the amount of deferred overhauls costs being amortized for the current period. For carriers which elect to continue accruing for aircraft overhauls for aircraft types acquired before January 1, 1976, as well as for other aircraft of the same type acquired after January 1, 1976, the related provisions and charges shall be recorded in the appropriate subaccounts of this account.

(b) This account shall be subdivided as follows by all carrier groups.

72.1 Airworthiness Reserve Provisions—Airframes.

Record here current provisions for effecting an equitable distribution of airframe overhaul costs between different accounting periods.

72.2 Airworthiness Reserve Charges—Airframes (Credit).

Record here credits for airframe overhaul costs incurred in the current period which have been charged against related airworthiness reserves.

72.3 Airframe Overhauls Deferred (Credit).

Record here airframe overhauls of the current period transferred to subaccount 1601.2 Unamortized Airframe Overhauls.

72.4 Amortization of Airframe Overhauls.

Record here the amount of deferred airframe overhaul costs amortized for the current period.

72.6 Airworthiness Reserve Provisions—Aircraft Engines.

Record here current provisions for effecting an equitable distribution of aircraft engine overhaul costs between different accounting periods.

72.7 Airworthiness Reserve Charges—Aircraft Engines (Credit).

Record here credits for aircraft engine overhaul costs incurred in the current period which have been charged against related airworthiness reserves.

72.8 Aircraft Engine Overhauls Deferred (Credit).

Record here airframe overhauls of the current period transferred to subaccount 1602.2 Unamortized Aircraft Engine Overhauls.

72.9 Amortization of Aircraft Engine Overhauls.

Record here the amount of deferred aircraft engine overhauls costs amortized for the current period.

73 Provisions for Obsolescence and Deterioration—Expendable Parts.

(a) Where reserves for loss in value of flight equipment expendable parts are established, provisions for accruals to such reserves shall be charged to this account and credited to balance sheet account 1311 Obsolescence and Deterioration Reserves—Expendable Parts in accordance with the provisions of that account.

(b) This account shall be subdivided as follows by all air carrier groups:

73.1 *Current Provisions.*

Record here provisions during the current period for losses in value of expendable parts.

73.2 *Inventory Decline Credits.*

Record here credits applicable to the current period for any adjustments for excess inventory reserve levels determined pursuant to section 6–1311.

74 Amortization.

(a) Record here amortization of deferred charges attaching to the air transportation services conducted by the air carrier which are not prepayments of recurrent expenses ordinarily requiring expenditures of working capital within one year.

(b) This account shall be subdivided as follows by all air carrier groups:

74.1 *Developmental and Preoperating Expenses.*

Record here amortization of the cost of projects carried in balance sheet account 1830 Developmental and Preoperating Costs as approved or directed by the Civil Aeronautics Board.

74.2 *Other Intangibles.*

Record here amortization of the cost of intangibles not provided for otherwise as approved or directed by the Civil Aeronautics Board.

75 Depreciation.

(a) Record here provisions for depreciation of property and equipment carried in balance sheet accounts 1601 through 1640, inclusive.

(b) This account shall be subdivided as follows:

75.1 Depreciation—Airframes.

Record here provisions for depreciation of property and equipment carried in balance subaccount 1601.1 Airframes.

75.2 Depreciation—Aircraft Engines.

Record here provisions for depreciation of property and equipment carried in balance sheet subaccount 1602.1 Aircraft Engines.

GROUP II AND GROUP III AIR CARRIERS

75.3 *Depreciation—Airframe Parts.*

Record here provisions for depreciation of spare airframe instruments and parts carried in balance sheet subaccount 1608.1 Airframe Parts and Assemblies.

75.4 *Depreciation—Aircraft Engine Parts.*

Record here provisions for depreciation of spare aircraft engine instruments and parts carried in balance sheet subaccount 1608.5 Aircraft Engine Parts and Assemblies.

ALL AIR CARRIER GROUPS

75.5 Depreciation—Other Flight Equipment.

Record here provisions for depreciation of property and equipment carried in balance sheet account 1607 Improvements to Leased Flight Equipment (exclusive of capitalized overhauls accounted for on a deferral and amortization basis) and balance sheet subaccount 1608.9 Other Parts and Assemblies. Group I air carriers shall also include in this subaccount provisions for depreciation of property carried in balance sheet account 1608 Flight Equipment Rotable Parts and Assemblies.

75.6 *Depreciation—Flight Equipment.*

This classification is established only for purposes of control by the Civil Aeronautics Board and shall include all charges to operating expenses for depreciation of flight equipment of all types and classes.

75.8 *Depreciation—Maintenance Equipment and Hangars.*

Record here provisions for depreciation of property and equipment carried in balance sheet account 1634, Maintenance and Engineering Equipment and balance sheet subaccount 1640.1 Maintenance Buildings and Improvements.

75.9 *Depreciation—General Ground Property.*

Record here provisions for depreciation of property and equipment carried in balance sheet accounts 1630 through 1640, other than account 1634, Maintenance and Engineering Equipment and subaccount 1640.1, Maintenance Buildings and Improvements.

76 Foreign Exchange Fluctuation Adjustments.

Record here gains or losses from transactions involving currency conversions resulting from normal, routine, day-to-day fluctuations in rates of foreign exchange in accordance with provisions of section 2-3. Gains or losses of a nonroutine abnormal character shall not be entered in this account but in a profit and loss account 85, Foreign Exchange Adjustments.

77 Uncleared Expense Credits.

(a) Record here credits to operating expenses, which have not been cleared to the objective accounts to which applicable.

(b) Each air carrier shall credit, or charge as appropriate, the objective account prescribed for each expense element which may be involved in distribution of expenses between separate reporting entities or nontransport divisions of the air carrier. At the option of the air carrier, either the individual applicable objective accounts or this account may be credited with amounts capitalized, charged against incidental services, or otherwise assigned to other than separate operating entities of the air carrier provided the aggregate credits to this account in each function do not, for any accounting year, distort the individual objective accounts of the function to which related and all expense credits applicable to complete individual transactions are consistently credited either to this account or the individual objective accounts to which related. Each air carrier using this account shall establish such standard practices as may be prescribed by the Civil Aeronautics Board or, in the absence of such action by the Civil Aeronautics Board, such standard practices as will prevent credits to this account from significantly distorting the individual objective accounts of each function to which related.

(c) This account shall not be credited with amounts applicable to objective accounts of the Flying Operations, Depreciation, and Direct Maintenance functions. Credits applicable to such functions shall be carried to the individual objective accounts to which applicable.

(d) This account shall be subdivided as follows by all air carrier groups:

77.8 *Uncleared Interchange Expense Credits.*

Record here credits to operating expenses, from operations performed for others under aircraft interchange agreements, which have not been cleared to the objective accounts to which applicable.

77.9 *Other Uncleared Expense Credits.*

Record here credits to operating expenses, from other than operations under aircraft interchange agreements, which have not been cleared to the objective accounts to which applicable.

78 Direct Maintenance—Flight Equipment.

This classification is established for purposes of control by the Civil Aeronautics Board and shall include all charges to operating expenses for maintenance of flight equipment of all types and classes.

79 Applied Burden Debit/Credit.

(a) This classification is established only for purposes of control by the Civil Aeronautics Board and reporting on Form 41 by air carriers, and shall reflect all maintenance burden applied in accordance with the provisions of section 24, schedule P-5 of this system of accounts and reports.

(b) This classification shall be subdivided as follows by all air carrier groups:

79.6 Applied Burden—Flight Equipment.
79.8 Applied Burden—General Ground Property.

Section 13 [Reserved]

APPENDIX IV
DISTRIBUTION OF ATA SYSTEM MAINTENANCE EXPENSES BY COMPONENTS FOR CALENDAR YEAR 1974

727 Aircraft component	% of sum of total
ATA 21	
AIRCONDITIONING–GENERAL	5.5
MULTIPLIER, APU BLEEDAIR FLOW	2.4
VALVE, FLOW CONT/ROL/PACK/SHUTOFF	3.4
CONTROLLER, AUTO PRESSURIZATION	8.0
VALVE, AIR CONDITIONING PRESSURE CONTROL OUTFLOW	6.9
MACHINE, AIR CONDITIONING, AIR CYCLE	16.6
THERMOSTAT	4.0
VALVE, ACCESSORY SYSTEMS PACK SHUTOFF	3.1
VALVE, WATER SEPARATOR CONTROL	2.4
FAN, GROUND AIR MOVER	5.7
REGULATOR, CABIN TEMPERATURE CONTROL	4.5
VALVE, AIR CONDITIONING AIR TEMPERATURE CONTROL	6.4
OTHER	31.2
ATA 22	
AUTO FLIGHT–GENERAL	8.0
PANEL, AUTO PILOT CONTROL	12.9
COMPUTER, AUTO PILOT PITCH	13.1
COMPUTER, AUTO PILOT ROLL	10.4
COUPLER	5.6
SERVO, AUTO PILOT STABILIZER TRIM CONTROL	15.9
VALVE, AUTO PILOT YAW DAMPER ACTUATOR	5.5
SENSOR, AUTO PILOT AIR DATA	6.8
SENSOR, CONTROL SURFACE TRIM AUTO PILOT	5.1
OTHER	16.0
ATA 23	
COMMUNICATIONS–GENERAL	3.0
TRANSCEIVER, HF	18.9
PANEL, VHF COMMUNICATIONS/YHF NAVIGATION CONTROL	7.0
RECEIVER, VHF COMMUNICATIONS	13.8
TRANSCEIVER, VHF	5.2
TRANSMITTER, VHF COMMUNICATIONS	3.4
AMPLIFIER, PASSENGER ADDRESS & ENTERTAINMENT	4.4
HANDSET, PASSENGER ADDRESS SYSTEM	6.4
HEADPHONE, FLIGHT INTERPHONE	3.2

MICROPHONE, FLIGHT INTERPHONE HAND	4.0
PANEL, FLIGHT INTERPHONE AUDIO SELECTOR	7.1
RECORDER, VOICE	10.8
OTHER	13.0

ATA 24

ELECTRICAL POWER–GENERAL	2.7
DRIVE, CONSTANT SPEED (CSD)	32.3
GENERATOR, ELECTRIC POWER SYSTEM AC	45.2
REGULATOR, AC GENERATION CONTROL VOLTAGE	2.7
CONTROL UNIT, AC GENERATION CONTROL–PHASE	2.8
BATTERY, DC NICAD	5.4
OTHER	8.8

ATA 25

SEAT, PILOT AND COPILOT	1.9
CONTROL, PASSENGER CABIN RECLINE	5.6
COVER, PASSENGER CABIN SEAT	3.3
TRAY, PASSENGER CABIN SEAT FOOD	1.8
RUG, MAIN CABIN AISLE	1.7
SHADE, PASSENGER CABIN WINDOW	2.1
BOX, PASSENGER CABIN GALLEY	3.5
DRAWER, PASSENGER CABIN GALLEY MODULE	6.1
FAN, GALLEY OVEN	2.9
MAKER, PASSENGER CABIN GALLEY COFFEE	24.3
NET, COCKPIT	2.0
SLIDE, PASSENGER CABIN EMERGENCY ESCAPE	5.4
OTHER	39.4

ATA 26

SENSOR, ENGINE FIRE DETECTION	48.7
OTHER	51.3

ATA 27

FLIGHT CONTROL–GENERAL	7.9
CONTROL UNIT, AILERON POWER	5.7
CONTROL UNIT, RUDDER POWER	3.7
COMPUTER, ELEVATOR FEEL	3.1
CONTROL UNIT, ELEVATOR POWER	5.8
CONTROL UNIT, ELEVATOR FEEL	3.2
ACTUATOR, JACK SCREW ASSEMBLY MAIN ELEVATOR	7.0
MOTOR, TRAILING EDGE, FLAP HYDRAULIC POWER	7.0
VALVE, TRAILING EDGE FLAP CONTROL	9.9

INDICATOR	2.6
ACTUATOR, FLIGHT SPOILER	3.7
ACTUATOR, LEADING EDGE FLAP CONTROL	2.0
ACTUATOR, LEADING EDGE SLAT CONTROL	14.5
SWITCH, LEADING EDGE FLAP	4.2
OTHER	24.6

ATA 28

FUEL–GENERAL	14.0
CONTROL-UNIT, FUEL VOLUMETRIC SHUT-OFF	17.1
MOTOR, ENG FUEL FEED BOOST PUMP	8.9
INDICATOR, FUEL QUANTITY	25.8
INDICATOR, FUEL QUANTITY TOTALIZER	8.0
OTHER	26.2

ATA 29

HYDRAULIC POWER–GENERAL	7.2
LINE, HYDRAULIC POWER PLUMBING	5.2
MAIN HYDRAULIC POWER SYSTEM, GENERAL	4.4
FILTER, MAIN HYDRAULIC SYSTEM	4.7
PUMP, MAIN ENGINE DRIVEN HYDRAULICS	31.9
MODULAR UNIT, MAIN HYDRAULIC SYSTEM	3.3
PUMP, MAIN HYDRAULIC "B" SYSTEM MOTOR DRIVEN	23.2
OTHER	20.1

ATA 30

VALVE, ENGINE NOSE COWL ANTI-ICE	20.3
CONTROLLER, WINDOW HEAT	23.4
OTHER	56.3

ATA 31

CLOCK, AIRCRAFT	24.4
MAGAZINE, FLIGHT DATA RECORDER	13.5
RECORDER, FLIGHT DATA	50.9
OTHER	11.3

ATA 32

LANDING GEAR–GENERAL	1.8
CYLINDER, MAIN LANDING GEAR SHOCK STRUT INNER	.5
CYLINDER, MAIN LANDING GEAR SHOCK STRUT OUTER	1.4
SHAFT, NOSE LANDING GEAR STRUT PIVOT	.4
STRUT, NOSE LANDING GEAR SHOCK	.2

ACTUATOR, MLG WHEEL WELL DOOR	.3
ACTUATOR, NLG RETRACTION	.5
BRAKE, MLG HYD ACTUATOR	37.8
VALVE, MLG HYD BRAKE LOCK OUT	.6
VALVE, LG HYD BRAKE	.4
VALVE, MLG WHEEL ANTISKID CONTROL	.6
TIRE, LG. WHEEL–GENERAL	.4
WHEEL, NLG (INCLS TIRE)	14.0
WHEEL, MLG (INCLS TIRE)	35.7
INDICATOR LG TIRES PRESSURE CHECK	1.1
SWIVEL, NLG WHEEL STEERING	.3
ACTUATOR, TAIL SKID	.4
OTHER	3.8

ATA 33

AIRCRAFT LIGHTING SYSTEM–GENERAL	11.4
LAMP, PASSENGER CABIN LIGHT	4.2
LIGHT, PASSENGER CABIN READING	5.3
LAMP, STAIRWAY/ENTRY LIGHT	3.1
LENS, WING LANDING/TAXI LIGHT	6.4
LIGHT, AIRCRAFT LANDING	5.1
LIGHT, MAXIMUM SAFETY	5.6
LIGHT, OSCILLATING NAVIGATION	15.8
CONTROLLER, ANTI COLLISION	3.2
LIGHT, ANTI COLLISION (ROTATING BEACON)	6.8
OTHER	33.1

ATA 34

TUBE, HEATED PITOT	1.3
COMPUTER, AIR DATA (CADC)	4.6
COMPUTER, PNEU AIR DATA ALTIMETER	2.6
INDICATOR, PNEU AIR DATA ALTIMETER	1.9
INDICATOR, PNEU AIR DATA IAS	.7
INDICATOR, PNEU AIR DATA ALTIMETER	.9
PANEL, ALTITUDE ALERT CONTROL	2.2
GYRO, REMOTE MAGNETIC COMPASS DIRECTIONAL	4.7
INDICATOR, RADIO MAGNETIC (RMI)	1.8
GYRO, ATTITUDE AND VERTICAL REFERENCE	11.8
INDICATOR, STANDBY ARTIFICIAL HORIZON	1.7
INDICATOR, HSI	2.3
INDICATOR, ATTITUDE DIRECTOR	13.8
RACK, FLIGHT DIRECTOR FLIGHT INSTRUMENT	1.0
RECEIVER, GLIDE SLOPE	3.5
ANTENNA, WEATHER RADAR	2.6
INDICATOR, WEATHER RADAR	5.0

TRANSCEIVER, WEATHER RADAR	7.3
ACCESSORY UNIT, WEATHER RADAR	1.5
INDICATOR, LOW RANGE RADIO ALTIMETER	1.7
TRANSCEIVER, LOW RANGE RADIO	1.7
PANEL, AIR TRAFFIC CONTROL, CONTROL	.8
TRANSCEIVER, ALTITUDE	2.4
INTERROGATOR, DME	6.7
RECEIVER, ADF	1.6
OTHER	13.7

ATA 35

BOTTLE, PASSENGER CABIN/FLIGHT COCKPIT OXYGEN	39.0
MASK, (INCLS HOSE AND MASK)	30.4
OTHER	30.6

ATA 36

VALVE, ENG 13TH STAGE PRESSURE MODULATOR	28.4
VALVE, ENG. BLEED AIR PRESSURE RELIEF	11.4
OTHER	60.2

ATA 38

WATER & WASTE–GENERAL	12.7
POTABLE WATER–GENERAL	18.1
PUMP, TOILET (INCLS MOTOR/FILTER)	23.6
OTHER	45.7

ATA 49

POWER UNIT AIRBORNE AUXILIARY (APU)	81.3
THERMOSTAT APU OVERHEAT	1.3
CONTROL UNIT, APU FUEL PUMP AND CONTROL	2.0
IGNITION UNIT, APU ENG	1.5
STARTER, APU ENG	.9
VALVE, APU BLEED AIR LOAD CONTROLLER	1.5
SWITCH, APU CONTROL	3.0
THERMOSTAT, APU BLEED AIR LOAD CONTROL	1.3
ACTUATOR, APU EXHAUST GAS OUTLET DOOR	1.8
OTHER	5.3

ATA 51

OTHER	100.0

ATA 52

DOORS–GENERAL	16.1
LANYARD, COCKPIT DOOR	7.7
LOCK	7.6
OTHER	68.6

ATA 53

FUSELAGE–GENERAL	15.2
RADOME, ACFT NOSE (ASSY)	28.2
OTHER	56.5

ATA 54

OTHER	100.0

ATA 55

TAB, RUDDER CONTROL	62.6
OTHER	37.4

ATA 56

WINDOW NBR 1 (ASSY–INCLS HEATER)	57.6
WINDOW NBR 3	21.2
WINDOW NBR 2 SLIDING (INCLS HEATER)	15.8
OTHER	5.3

ATA 57

FAIRING, TRAILING EDGE FLAP	7.2
FLAP, TRAILING EDGE FLAP AFT	6.2
FLAP, TRAILING EDGE FLAP FORE	27.1
OTHER	59.5

747 Aircraft component	% of sum of total
ATA 21	
VALVE, FLOW CONTROLLER/PACK/SHUT-OFF	5.5
CONTROLLER, AUTO PRESELECTION	4.1
VALVE, AFT CARGO COMPARTMENT OVERBOARD	11.5
VALVE, AFT CARGO COMPARTMENT HEAT CONTROL	11.6
MACHINE, AIR CONDITIONING AIR CYCLE	19.1
SENSOR, AIR CYCLE MACHINE MASS AIR FLOW	6.2
ACTUATOR, RAM AIR INLET/EXHAUST DOOR	11.2
OTHER	30.6
ATA 22	
MODULE, AUTO PILOT MONITOR/LOGIC	9.3
PANEL, AUTOPILOT MODE SELECTOR	10.0
TRIM UNIT, AUTO STABILIZER	4.5
COMPUTER, AUTO PILOT PITCH	34.1
COMPUTER, YAW DAMPER	4.0
COMPUTER, AUTOPILOT ROLL	21.9
COMPUTER	4.6
OTHER	11.7
ATA 23	
COMMUNICATIONS–GENERAL	.6
SWITCHING UNIT	.6
TRANSCEIVER, HF COMMUNICATIONS SYSTEM	2.2
TRANSCEIVER, VHF/VHF	.4
BOX, PASSENGER ENTERTAINMENT/CALL	80.2
MULTIPLEXER, PASSENGER ENTERTAINMENT MAIN	.3
MULTIPLEXER, PASSENGER ENTERTAINMENT SUBSIDIARY	.5
REPRODUCER, PASSENGER ENTERTAINMENT MUSIC TAPE	.8
CONTROL UNIT, PASSENGER CABIN SEAT ENTERTAINMENT/CALL	6.0
HANDSET, CABIN INTERPHONE	4.0
HANDSET, LOWER LOBE GALLEY INTERPHONE	1.2
OTHER	3.1
ATA 24	
ELECTRICAL POWER–GENERAL	2.3
DRIVE, CONSTANT SPEED (CSD)	33.0
GENERATOR, ELEC PWR SYS AC	33.9
CONTROL UNIT, AC GENERATION CONTROL PHASE	11.0
CONTROL UNIT, AC GENERATION BUS	3.1
BATTERY, DC LEAD ACID	9.9
OTHER	6.8

ATA 25

EQUIPMENT & FURNISHINGS–GENERAL	3.8
SEAT, OBSERVER	.6
CAP, PASSENGER CABIN SEAT ARMREST	2.7
CONTROL, PASSENGER CABIN SEAT RECLINING	.8
COVER, PASSENGER CABIN SEAT	.9
LOCK, PASSENGER CABIN SEAT MECHANICAL	11.1
SEAT, PASSENGER CABIN TOURIST	3.2
SEAT, PASSENGER CABIN SWIVEL	.5
SERVICE UNIT, PASSENGER (PSU)	6.3
DOOR, ATTENDANT STATION SEAT STOWING	.6
SHADE, PASSENGER CABIN WINDOW ASSY)	1.7
RABLE, PASSENGER CABIN TRIM	.7
DOOR, MAIN CABIN GALLEY OVEN	2.1
DRAWER, PASSENGER CABIN GALLEY REFRIGERATION UNIT	.7
MAKER, PASSENGER CABIN LOWER LOBE GALLEY COFFEE	8.4
OVEN, PASSENGER CABIN/LOWER LOBE GALLEY	2.3
PANEL, GALLEY POWER CONTROL	4.1
REFRIGERATOR, LOWER LOBE GALLEY SERVICE	1.5
REEL, SERVING CART ELEC CORD RETURN	.8
WIRING, PASSENGER CABIN CART (EXTENSION)	.6
ACTUATOR, LOWER LOBE GALLEY ELEVATOR	4.5
ELEVATOR, LOWER LOBE GALLEY PERSONNEL	.6
GUARD, LOWER LOBE GALLEY CART ELEVATOR	.8
GUIDE, LOWER LOBE GALLEY ELEVATOR DRIVE	2.8
MOTOR, LOWER LOBE GALLEY ELEVATOR ACTUATOR	.6
ACTUATOR, CARGO COMPARTMENT CONVEYOR WHEEL RETRACTABLE	1.0
PANEL, CARGO COMPARTMENT CARGO HANDLING CONTROL	1.4
RESTRAINT, CARGO COMPARTMENT DOOR RETRACTABLE	1.3
DRIVE UNIT, CARGO COMPARTMENT CONVEYOR WHEEL DRIVE	6.3
POWER UNIT, LOWER LOBE GALLEY CARGO HANDLING	6.7
GENERATOR, EMERGENCY PASSENGER SLIDE INFLATABLE GAS	1.3
SLIDE, PASSENGER CABIN EMERGENCY ESCAPE	1.5
SLIDE, OVER WING ESCAPE	.8
RAFT, LIFE	1.1
OTHER	16.0

ATA 26

SENSOR, ENG FIRE DETECTOR DUAL	16.4
BOTTLE, ENG FIRE EXTINGUISHER	17.2
BOTTLE, APU FIRE EXTINGUISHER	11.7
OTHER	54.8

ATA 27

CONTROL UNIT, CONTROLLER HYDRAULIC	4.4
CONTROL UNIT, AILERON POWER	7.0
CONTROL UNIT, RUDDER POWER	10.1
CONTROL UNIT, RUDDER RATIO	2.1
CONTROL UNIT, ELEVATOR POWER	2.5
TRANSMISSION, TRAILING EDGE FLAP DRIVE	36.3
MODULE TRAILING EDGE FLAP CONTROL	6.2
DRIVE UNIT, LEADING EDGE FLAP PNEUMATIC	26.3
OTHER	15.1

ATA 28

FUEL–GENERAL	10.4
MOTOR, ENG FUEL FEED BOOST PUMP	9.9
INDICATOR, FUEL QUANTITY CENTER MAIN	15.5
OTHER	64.1

ATA 29

HYDRAULIC POWER–GENERAL	8.6
PUMP, ENGINE DRIVEN/AIR DRIVEN HYDRAULIC	23.5
VALVE, AIR DRIVEN HUDRAULIC PUMP & MODULATION CONTROL	4.7
DRIVE UNIT, AIR DRIVEN HYDRAULIC PUMP	29.4
DETECTOR, HYDRAULIC FLUID TEMPERATURE OVER HEAT	7.4
TRANSMITTER, HYDRAULIC QUANTITY	5.4
OTHER	21.1

ATA 30

VALVE, NOSE COWL SOLENOID CONTROLLED PRESSURE	42.2
OTHER	57.8

ATA 31

RECORDER, DIGITAL FLIGHT DATA	28.7
OTHER	71.3

ATA 32

LANDING GEAR–GENERAL	1.3
ACTUATOR, MLG DOOR EXTENSION/RETRACTION	.4
ACTUATOR, MLG TRUCK	.6
ACTUATOR, MLG DOOR EXTENSION/RETRACTION	.8
BRAKE, MLG HYD. ACTUATED	27.0
CARD, ANTISKID CONTROL/UNIT WHEEL	.5

VALVE, LG ANTISKID NORMAL/RESERVE	.9
WHEEL, NLG (INCLS TIRE)	10.9
WHEEL, MLG (INCLS TIRES)	53.1
INDICATOR, LG TIRE PRESSURE CHECK	.4
VALVE, NLG WHEEL STEERING METERING	.4
ACTUATOR, MLG STEERING	1.2
OTHER	2.5

ATA 33

AIRCRAFT LIGHTING SYSTEM–GENERAL	7.1
BALLAST, PASSENGER CABIN FLOOR LIGHT	3.3
LIGHT, PASSENGER CABIN READING	2.9
DECODER, PASSENGER SERVICE UNIT (PSU) PASSENGER CALL	11.6
TIMER, SERVICE ZONE COLUMN DECODER	11.7
LIGHT, AIRCRAFT LANDING	4.3
LIGHT, ANTI COLLISION (ROTATING BEACON)	4.6
POWER SOURCE, PASSENGER CABIN LIGHTED EMERGENCY SIGN	2.6
LIGHT, EMERGENCY EXIT	9.9
LIGHT, DOOR EXIT	5.1
LIGHT, LOWER LOBE GALLEY EMERGENCY	3.6
POWER, SUPPLY, OVERWING EMERGENCY LIGHT	3.1
LIGHT, PASSENGER CABIN PERSONAL ILLUMINATION	7.2
POWER SUPPLY, EMERGENCY PERSONAL LIGHT	3.1
OTHER	20.0

ATA 34

NAVIGATION–GENERAL	1.1
TUBE, HEATED PITOT-STATIC	2.1
COMPUTER, AIR DATA (CADC)	5.1
INDICATOR, PNEUMATIC AIR DATA ALTIMETER	2.0
INDICATOR PNEUMATIC AIR DATA MACH NO. AIR SPEED	2.4
INDICATOR–VOR/ILS RADIO MAGNETIC (RMI)	2.5
INDICATOR, HSI	2.0
INDICATOR, ATTITUDE DIRECTOR	2.5
ANTENNA, WEATHER RADAR	1.0
INDICATOR, WEATHER RADAR	3.2
TRANSCEIVER, WEATHER RADAR	2.7
INDICATOR, LOW RANGE RADIO ALTIMETER	1.4
TRANSCEIVER, LOW RANGE RADIO ALTIMETER	1.2
GYRO, INS ATTITUDE/HEADING SENSOR UNIT	2.1
PANEL, INS CONDITION/DISPLAY	1.6
NAVIGATION UNIT, INS	50.7
RECEIVER, VHF NAV/VOR/LCLER	1.8
INDICATOR, DME (T) MILES TO GO	5.4
INTERROIATOR, DME (T)	2.7
OTHER	6.7

ATA 36

CONTROL, 15TH STAGE BLEED AIR	6.4
VALVE, 8TH STAGE BLEED AIR	11.4
VALVE, ENG 15TH STAGE BLEED AIR	23.7
VALVE, ENG BLEED AIR PRESSURE RELIEF	6.1
VALVE, PYLON SHUT-OFF PRESSURE REGULATION	8.4
CONTROLLER, BLEED AIR TEMP/PRES, SENSOR	5.5
EXCHANGER, ENG BLEED AIR HEAT	29.5
OTHER	9.2

ATA 38

WATER AND WASTE–GENERAL	15.1
PUMP, TOILET (INCLS MOTOR/FILTER)	14.3
OTHER	70.6

ATA 49

AIRBORNE AUXILIARY POWER–GENERAL	1.3
POWER UNIT (APU)	76.4
ACTUATOR, APU AIR INLET DOOR	2.3
PUMP, APU ENG FUEL (INCLS FILTER)	1.1
BATTERY, APU STARTING–LEAD ACID	9.1
STARTER, APU ENGINE	2.9
VALVE, APU BLEED AIR LOAD CONTROL	1.6
CONTROLLER, APU TURBINE	1.2
OTHER	4.2

ATA 52

DOORS–GENERAL	29.7
OTHER	70.3

ATA 53

FUSELAGE–GENERAL	49.3
OTHER	50.7

ATA 54

OTHER	100.0

ATA 56

WINDOW–GENERAL	2.9
WINDOW, ASSY (INCLS HEATER)	95.6
OTHER	1.5

ATA 57

FLAP, TRAILING EDGE FLAP FORE	21.9
FLAP, LEADING EDGE	56.4
OTHER	21.8

APPENDIX V

LINE MATERIAL DOLLARS SUMMARY OF THE 70 HIGH COST MATERIALS EXPENDED DURING 1975 BY AAL ON ALL MODELS

Name	Expended material No.	$
Bolts	337 951	74 975.83
Bottle	30 593	23 835.07
Bracket	2 338	60 498.36
Bulb	2 525	21 044.13
Bushing	13 435	21 295.80
Cable	20 973	83 773.67
Cap	21 831	98 777.68
Clamp	20 233	14 032.90
Cleaner	8 440	21 296.85
Clip	14 026	24 225.83
Connector	1 123	25 223.24
Container	1 780	72 831.99
Control	2 931	64 366.97
Cover	33 851	552 754.74
Decal	11 673	19 763.21
Door	3 963	468 799.90
Duct	257	68 764.33
Element	8 591	100 160.33
Filter	3 921	25 382.47
Fitting	5 012	59 943.58
Gasket	16 695	19 228.79
Gloves	34 680	26 171.01
Guide	3 179	40 715.45
Handle	5 753	34 598.67
Harness	713	65 364.87
Hinge	10 136	103 120.56
Hose	2 154	46 726.41
Igniter	3 099	73 584.16
Kit	2 595	57 787.51
Lamp	279 907	275 133.32
Latch	8 627	73 967.64
Lens	5 076	23 501.35
Light	2 124	37 110.44
Link	2 274	50 223.01
Mask	7 963	22 964.01
Nozzle	140	24 313.06
Nut	187 218	43 910.25
Packing	56 100	37 325.29
Pallet	624	235 764.62
Panel	826	90 941.94

Name	No.	Expended material $
Pin	109 830	33 788.14
Placard	40 795	21 746.91
Plate	7 401	56 446.96
Plug	10 619	59 826.99
Relay	1 079	62 749.40
Retainer	8 696	42 854.33
Rivet	486 131	21 492.88
Rod	3 299	51 167.67
Roller	4 337	35 211.39
Rug	8 975	392 012.49
Screw	594 475	18 922.54
Seal	31 014	150 031.33
Sensor	127	28 586.60
Shaft	624	24 520.95
Sheet	11 682	47 971.26
Shield	1 822	44 951.58
Shroud	2 121	30 094.52
Spreader	399	35 079.83
Spring	13 495	19 235.68
Strap	48 072	64 376.49
Support	1 307	69 180.73
Switch	6 693	148 218.65
Tape	38 918	137 060.51
Transistor	3 435	33 486.28
Tray	573	34 056.21
Tube	7 019	117 272.32
Valve	3 497	44 147.37
Washer	366 510	19 874.58
Window	175	96 264.44
Windshield	159	314 400.04
SUBTOTAL	2 988 609	5 530 228.51
GRAND TOTAL	3 829 441	8 087 876.84

APPENDIX VI

SCHEDULE DELAYS AND CANCELLATIONS

1.0 COST OF DELAYS AND CANCELLATIONS

A typical design trade study in which delay and cancellation costs may be a significant factor involves choosing the correct balance of the cost consequences of delays and cancellations with their cost of prevention. The costs associated with delays, excluding the cost of correcting the delay cause, include:

(a) Extra crew costs

(b) Additional passenger handling

(c) Lost passenger revenue

The typical costs placed on dispatch delays by American Airlines and their distribution are shown in table 21 and figure 122.

Table 21.—Average Cost Per Delay (1976 \$)—American Airlines

	Length of delay, minutes		
	0-29	30-59	⩾60
747-123	\$210	\$535	\$2154
DC-10-10	170	440	1760
707-123B	120	330	1530
707-323B/C	125	340	1600
707-323C (freighter)	120	270	650
747-123 (freighter)	170	420	1700
727-023	110	270	1170
727-223	120	280	1340

The tolerance range on table 21 is approximately ±20%.

Other airlines have also established dollar values for delays and, in addition, The Boeing Commercial Airplane Company has developed a method of costing delays (reference 11). Table 22 is taken from Appendix III of reference 11 and illustrates the diversity of opinion on the cost of a delay that exists within the industry.

Table 22.—Comparison of the Cost of Delays (1976 \$) for a 1-Hour Delay of a 747

Airline A	Delay Cost =	\$ 115
Airline B		\$ 570
Airline C (American Airlines)		\$ 712
Airline D		\$1140
Airline E		\$1927
Boeing Method		\$1510

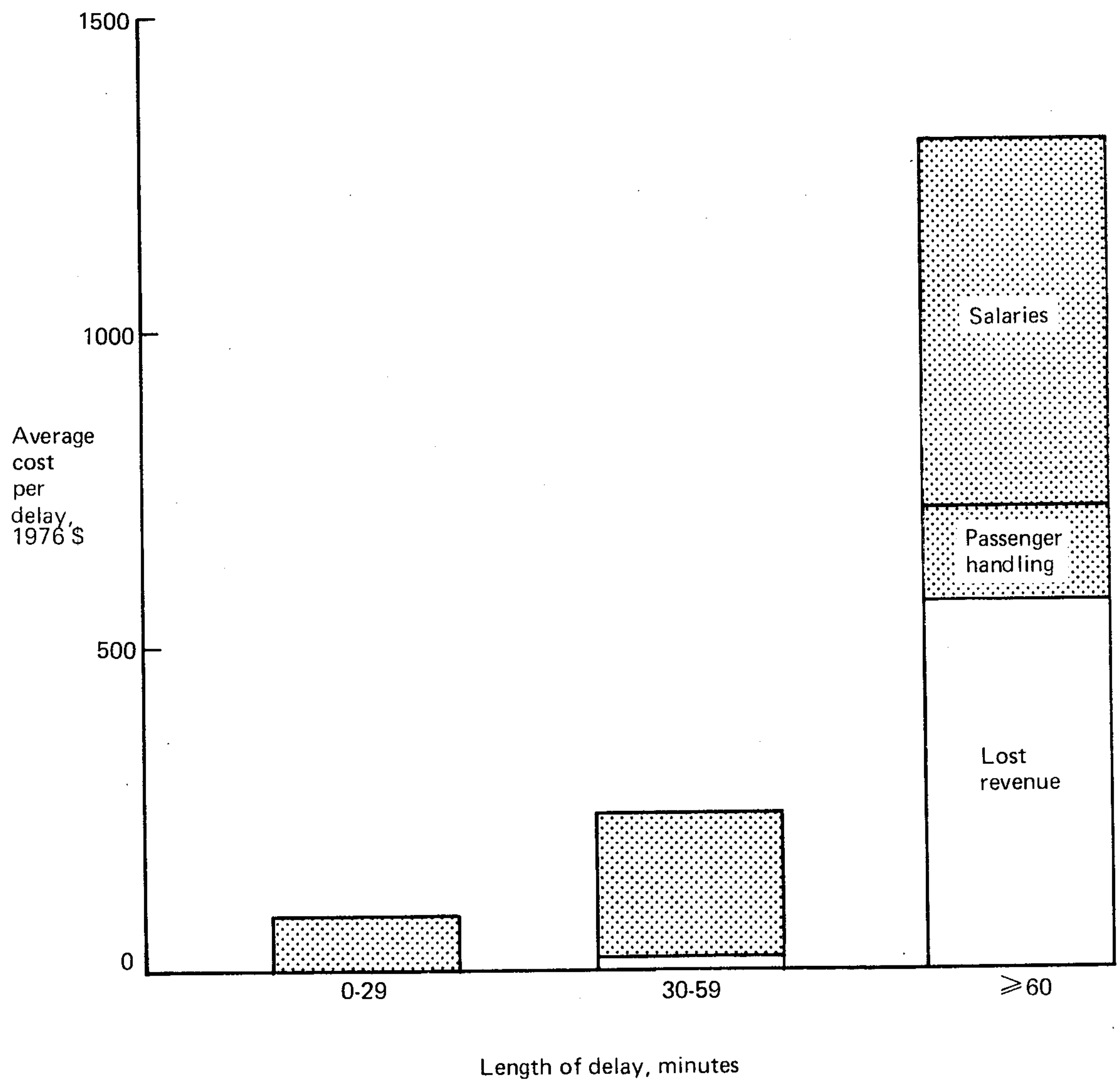


Figure 122.—American Airlines Sources of Delay Costs

The costs associated with a cancellation are those which occur during the delay prior to the cancellation as well as those associated with the cancellation itself (reference figure 123). Table 23 provides the cost of cancellation (including prior delay) used by American Airlines.

Table 23.—Average Cancellation Costs (1976 $)

747-123	$2800
DC-10-10	$2300
707-123B	$2000
707-323B/C	$2100
707-323C (freighter)	$ 850
747-123 (freighter)	$2240
727-023	$1500
727-223	$1750

The tolerance range on table 23 is approximately ±20%.

Certain of the tangible operating costs associated with actually flying (operating) a scheduled trip are eliminated when a cancellation occurs: for example, fuel and flight time related maintenance costs. An operating cost that may not be eliminated by a cancellation is the flight crew cost. (They are paid for a scheduled trip even if it is not operated.)

Lost revenue (which is not actually a cost) is subject to wide variations depending on passenger load and route system: for example, an anticipated low load factor could generate insufficient revenue to cover the cost of operating a trip, and a cancellation would result in more cost saved than revenue lost with less total loss to the airline. Conversely, the cancellation of a trip to a destination without a great deal of service (e.g., a remote island resort) could cause additional passenger handling expenses but noloss of revenue since the passenger would wait for the airline's next flight. As a result of these factors, there are considerable differences of opinion as to the cost of cancellations. So far as is known, no rigorous attempt has been made to arrive at a better resolution of these costs.

2.0 FREQUENCY AND TYPES OF DELAYS AND CANCELLATIONS

American Airlines divide delays into the following ten categories:

a. Late arrival from another station–includes late arrival from another station for one or more of the following causes.

b. Maintenance–Includes holds to correct airplane mechanical troubles, and the placarding of inoperative or missing equipment on the MEL.

c. Passenger service–Includes late arriving passengers, customs delays, and late connecting flights.

d. Cargo/cabin service–Includes late freight handling, cargo searches, holds for cargo connections, and cabin service.

e. Ground equipment–Includes delays due to unavailable ground equipment or terminal facilities.

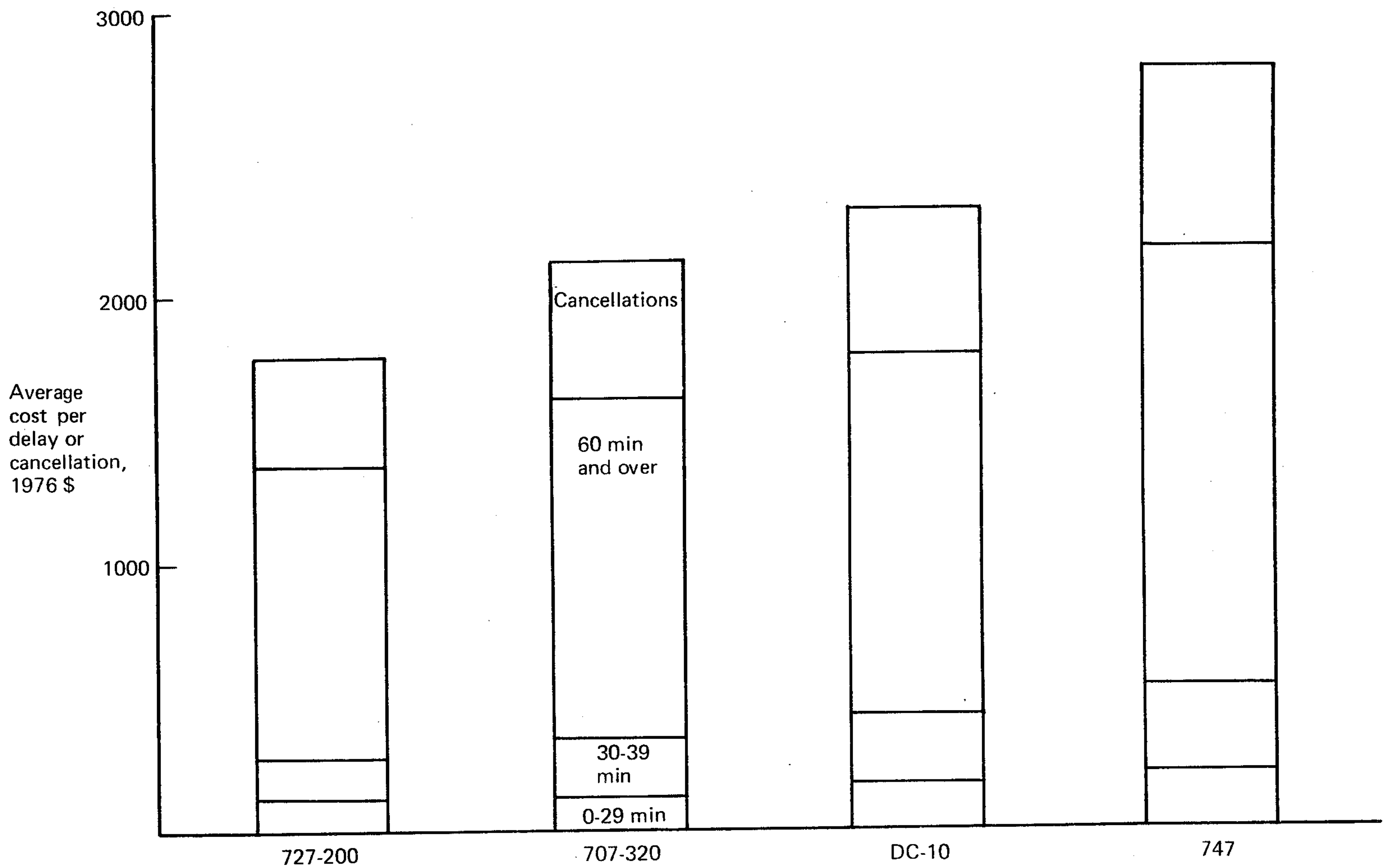


Figure 123.—American Airlines Delay and Cancellation Cost Factors For Specific Aircraft

f. Stores—Includes holds due to shortages of parts or defective parts from stores.

g. Flight crew—Includes late crew (flight crew and/or flight attendants), crew initiated precautionary checks, and restricted article processing procedures.

h. Weather—Includes airplane deicing, equipment shortages due to weather, and airport closures or restrictions.

i. Late equipment—Includes airplane late from hangar and service equipment shortages.

j. Other—Includes ground based air traffic control delays, unscheduled work stoppages, and other gate hold causes.

The occurrences per 100 revenue departures for each category for American Airlines fleet is shown in table 24 for example purposes.

Table 24.—Delay Category Occurrences Per 100 Departures (Delays Over One Minute), (American Airlines Fleet, 1973 Through 1975 Experiences)

• Late arrivals from another station	10.88
• Maintenance	2.75
• Passenger service	6.72
• Late cargo and cabin service	5.85
• Ground equipment	1.87
• Stores and parts shortages	.21
• Late crew and crew caused delays	.55
• Weather	3.50
• Airplane late from hangars	2.70
• Other	2.46

There is little the designer can do about late arriving passengers, cargo, or crew. However, delays due to the remaining causes listed in table 24 can be influenced by airplane design characteristics, such as door locations, component failure rate, system redundancy, and maintenance elapsed time. In addition, scheduling, facility utilization, etc., which are under control of the airline, also affect delay rate.

Figures 124, 125, and 126 provide an awareness of the influence delays and cancellations can have on the direct maintenance and operating costs of an airline, and the distribution of the delay and cancellations by category and time frame.

Analysis of all airplane types in the American Airlines fleet showed that most delay categories appeared to be a function of airplane size, as measured by the number of spec seats. Table 25 provides linear regression formulas for each of the delay and cancellation categories of table 24. These formulas should not be extrapolated beyond the limits of the data analyzed, namely fewer than 100 spec seats or more than about 450 spec seats.

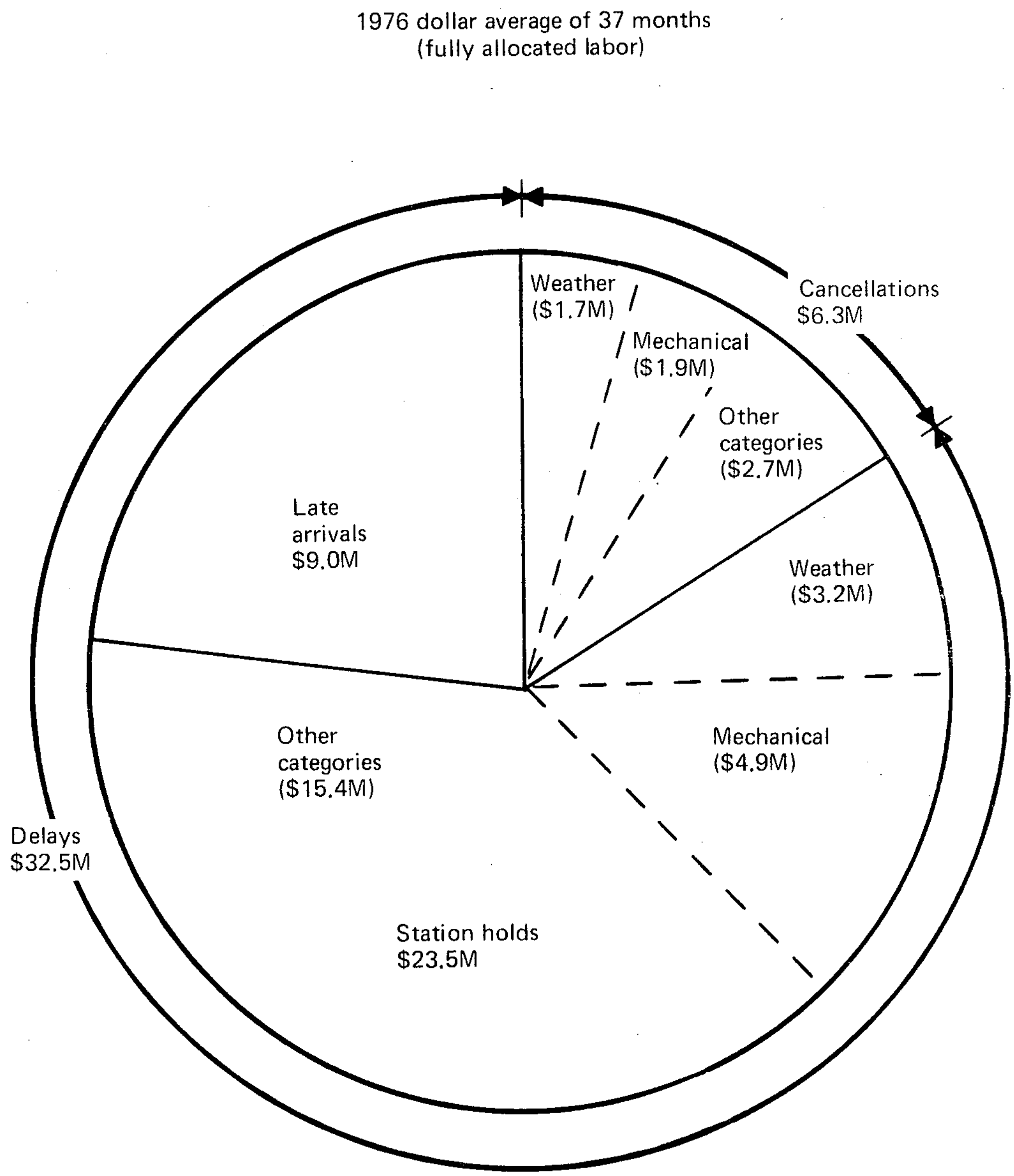
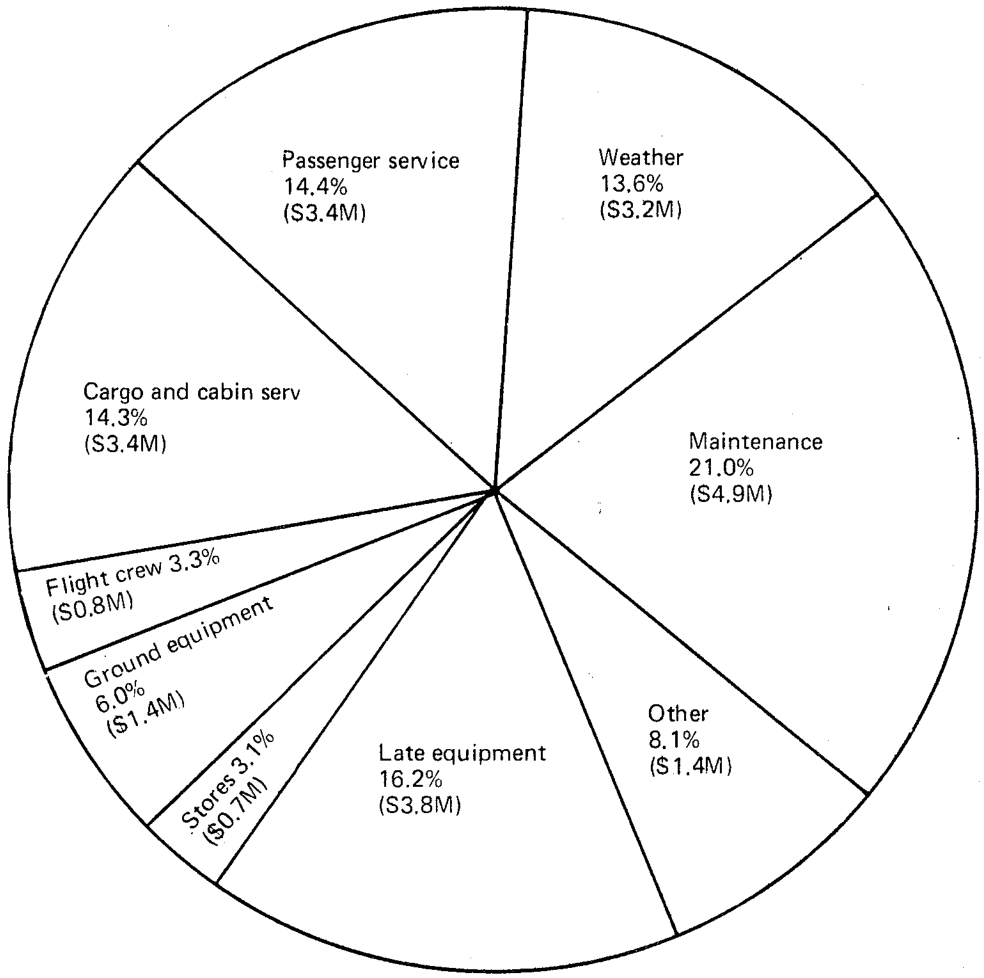


Figure 124.—Annual Cost of Delays and Cancellations—American Airlines Fleet



(Fully allocated labor 1976 $)

Total = $23.5 million

Figure 125.—Distribution of American Airlines Fleet Station Hold Costs

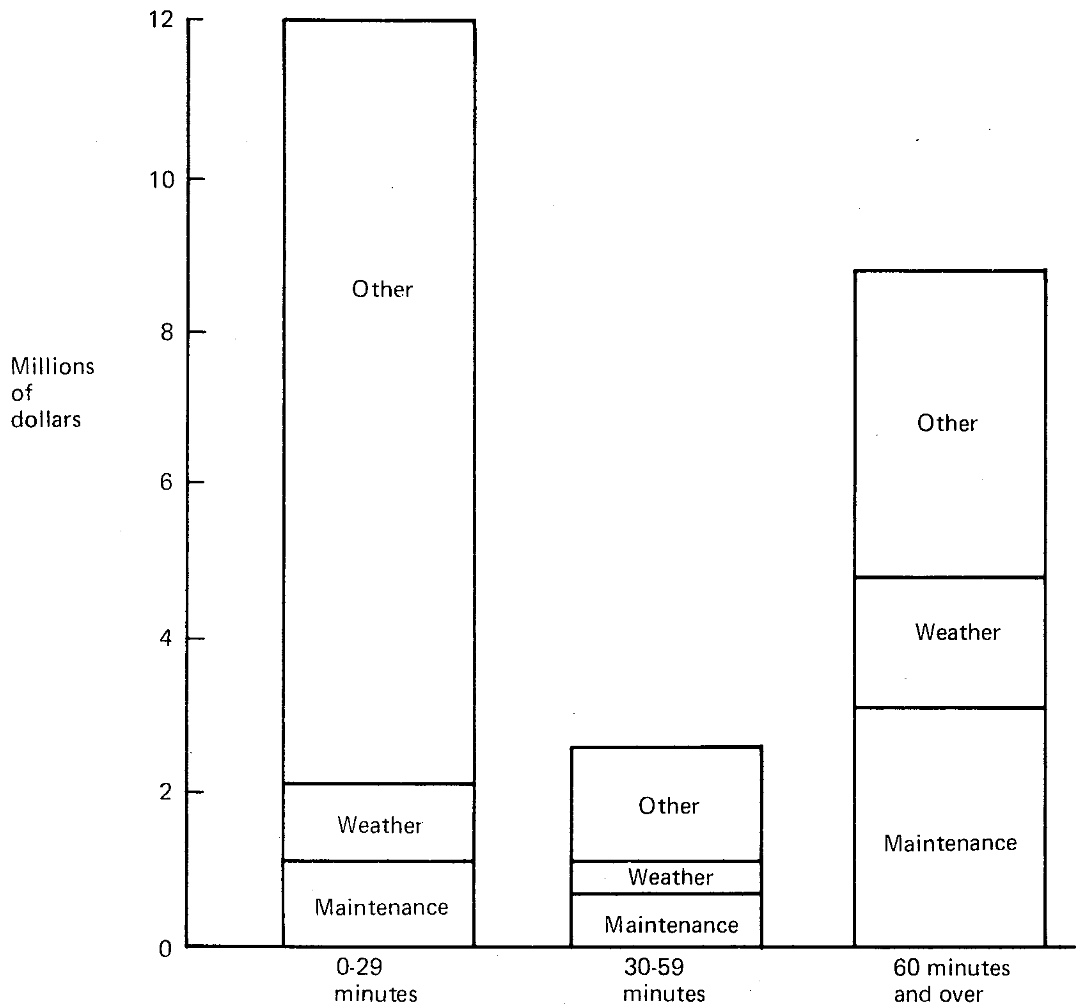


Figure 126.—Cost of Station Holds—AAL Fleet, 1972-1975 Annual Average

The delay and cancellation categories which are not necessarily a function of seat count, are marked with an asterisk in table 25.

Table 25.—Delays and Cancellations Per 100 Departures (Y) As a Function of Seats (X) (For X Between 100 and 450)

Delay and cancellation category	Relationship	Coefficient of determination
Late arrivals from another station	Y = 12.374 – 0.0232X	0.76*
Maintenance	Y = 2.134 + 0.011X	0.69
Passenger service	Y = 2.763 + 0.014X	0.94
Late cargo and cabin service	Y = 6.359	0.18*
Ground equipment	Y = 0.486 + 0.013X	0.91
Stores and parts shortages	Y = -0.020 + 0.002X	0.79
Late crew and crew caused delays	Y = 0.420 + 0.001X	0.69
Weather	Y = 3.341	0.33*
Airplane late from hangars	Y = 1.002 + 0.01X	0.95*
Other	Y = 0.555 + 0.019X	0.90
All causes	Y = 31.258 + 0.053X	0.88

In table 25 and subsequent tables, the coefficient of determination R^2 is a measure of the prediction accuracy and strength of association.

$R^2 = (Y^1 - \overline{Y})^2/(Y - \overline{Y})^2$

Y^1 = estimated values of Y

$\overline{Y}$ = mean value of Y

Y = actual values of Y in sample

A coefficient of determination of 1.0 would be a perfect fit of data and the derived relationship. Coefficients less than 0.6 in general indicate a relationship which is not substantiated. However, good correlation does not necessarily imply a rational physical relationship. For instance, there is no apparent relationship between airplanes late from the hangar and airplane size as measured by number of seats, yet the derived relationship has an index of determination of 0.95 (table 25).

It should also be noted that the contents of table 25 are only valid if the correlation between number of seats follows the historical norm of the analyzed data: for example, the equations in table 25 would not necessarily be valid for a wide body long-range airplane operated on short stage lengths.

As might be expected, the frequency of delays and cancellations shows a steady improvement with time. The mechanical delay data for American Airlines plotted in figure 127 proves to be similar to that of other operators, illustrated by figure 128. No attempt was made to establish if similar characteristics exist in individual airplane systems and equipment.

In figure 127, the historical progress of American Airlines is shown for dispatch of their various airplanes within 5 minutes of scheduled departure. This is considered to be "on time" for statistical

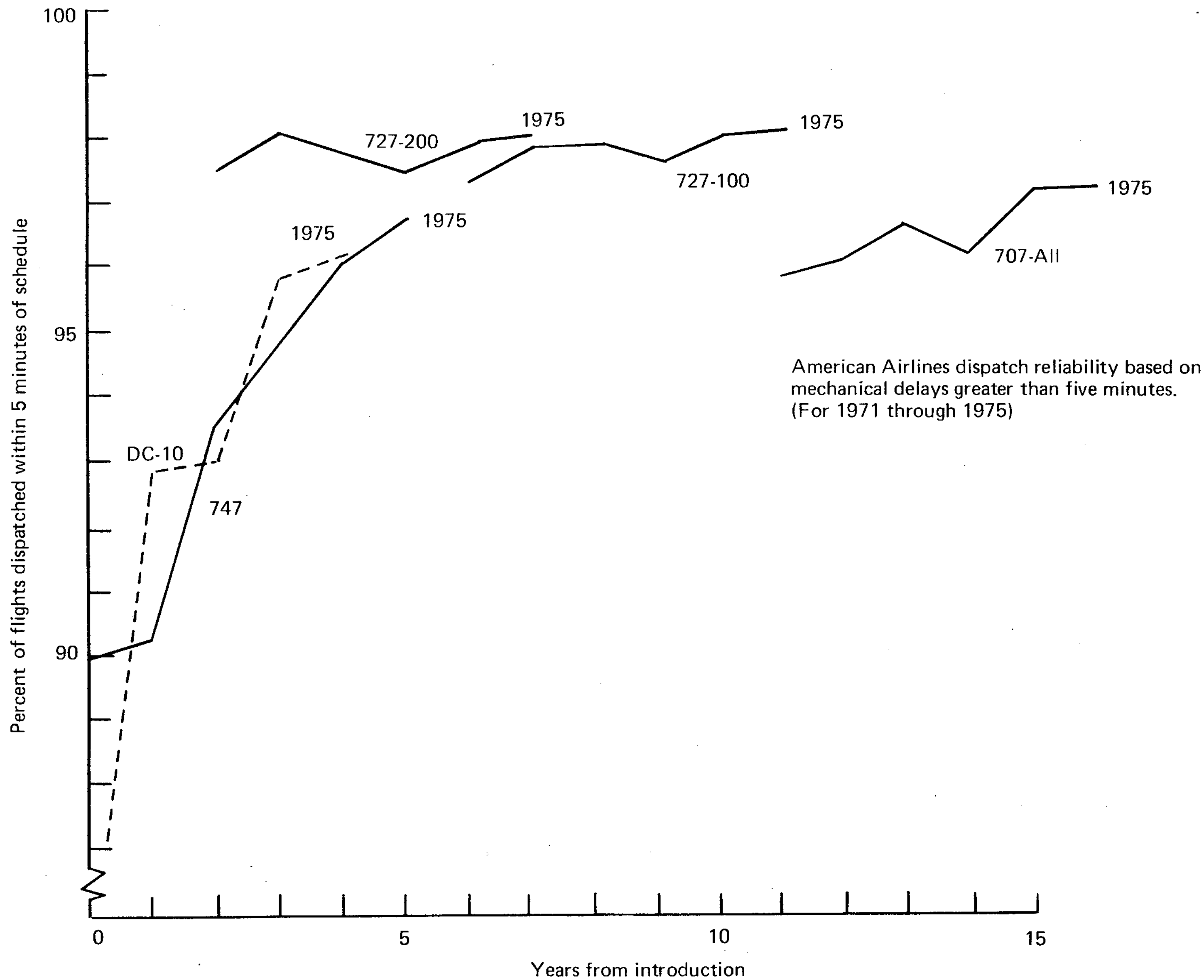


Figure 127.—Mechanical Dispatch Reliability Growth

record keeping purposes. Figure 128, showing dependability for departures within 15 minutes, suggests that American Airlines is not dissimilar to other domestic operators with respect to improving airplane dispatch reliability (and maintenance efficiency) as a function of length of service.

3.0 FREQUENCY OF MECHANICAL DELAYS, CANCELLATIONS AND MINIMUM EQUIPMENT LIST DISPATCHES

American Airlines defines a mechanical delay as a maintenance caused delay which exceeds five minutes. Mechanical delays are a function of technology and quality of design and manufacture, as well as airline operational policies and skill levels associated with scheduling and maintenance. It is not easy to separate operational and technological dependencies on the basis of a single airline and separation is not readily apparent even with a larger sample of airlines. Nevertheless, in the cases which follow, some technological dependencies are evident and can be used with caution in design studies as shown in the example of paragraph 3.7.

Implicit in the design technology of all the airplanes analyzed is the ability to dispatch airplanes with certain components either inoperative or with restrictions on their use, and thereby either avoid or minimize the cost consequences of delays and cancellation.

The means for accomplishing this is the Minimum Equipment List (MEL) procedure. This is a procedure, negotiated between individual airlines and the FAA, whereby safety of flight is shown to be not compromised with certain inoperative or missing items. It recognizes the airline's maintenance program and usually calls for corrective maintenance after some specified time limit. The Federal Aviation Agency approved Minimum Equipment Lists provide details of the exceptions to a fully serviceable condition which are acceptable when safety is not degraded.

Figure 129 shows the frequency of MEL usage, by aircraft type, by ATA system in American Airlines for a 12 month period. An item of interest is the FAA requirement to record the frequency of aircraft dispatch with the APU (System 49) and thrust reversers (System 78) inoperative, even though neither of these systems are required for airplane certification (certification of an aircraft's landing performance is not based on the use of thrust reversers).

Relationships for the rate of occurrence of mechanical delays and cancellations are provided in table 26, and for avoidance of delays by invoking the Minimum Equipment List, in table 27. The comments and cautions accompanying table 25 in paragraph 3.3 apply equally to tables 26 and 27. It will be seen that the parameters which affect mechanical delays are not necessarily the ones which affect maintenance cost and in a number of cases no satisfactory relationship could be found. Explanations of the parameters used are provided in section 3.

Figure 130 shows a relationship between mechanical reliability and flight length described empirically by $Y = 99.86 - 1.073x$ with coefficient of determination of 0.69.

This led to an attempt to correlate delays against flight length for individual ATA Systems. As shown in tables 26 and 27, there are exceptions where it is not possible to establish this correlation.

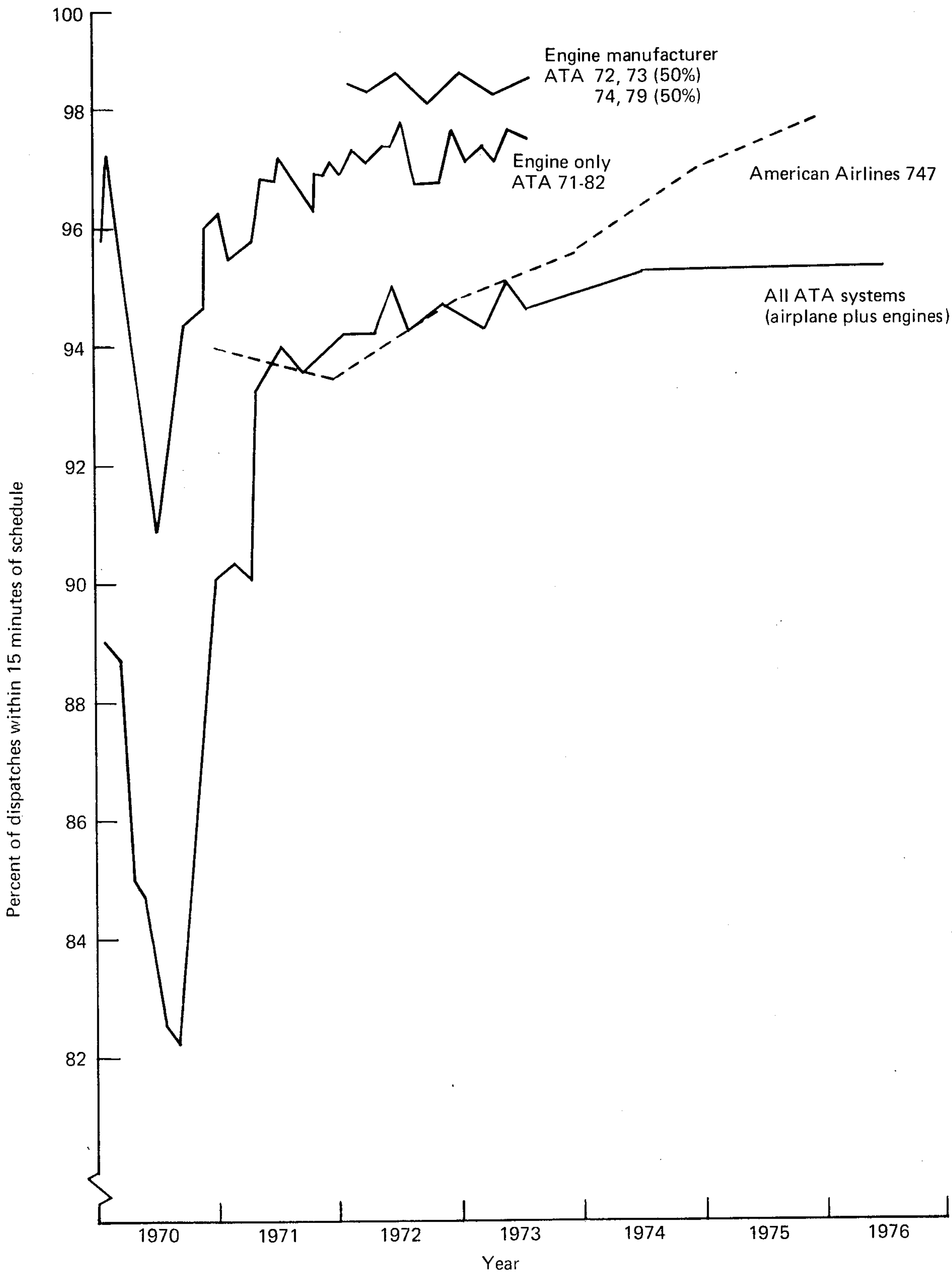


Figure 128.—All Operators 747 Mechanical Dispatch Reliability

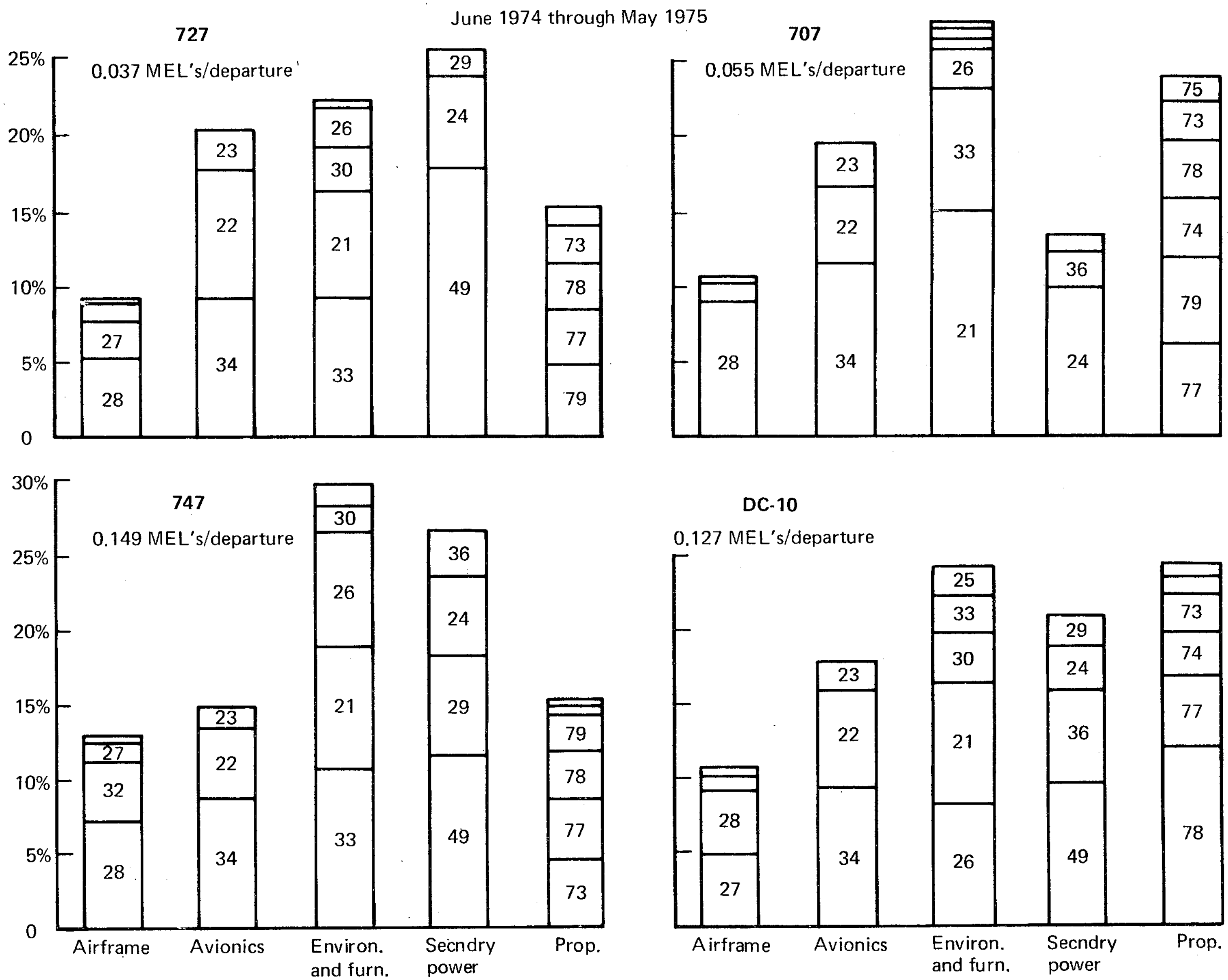


Figure 129.—American Airlines Minimum Equipment List Usage Distribution

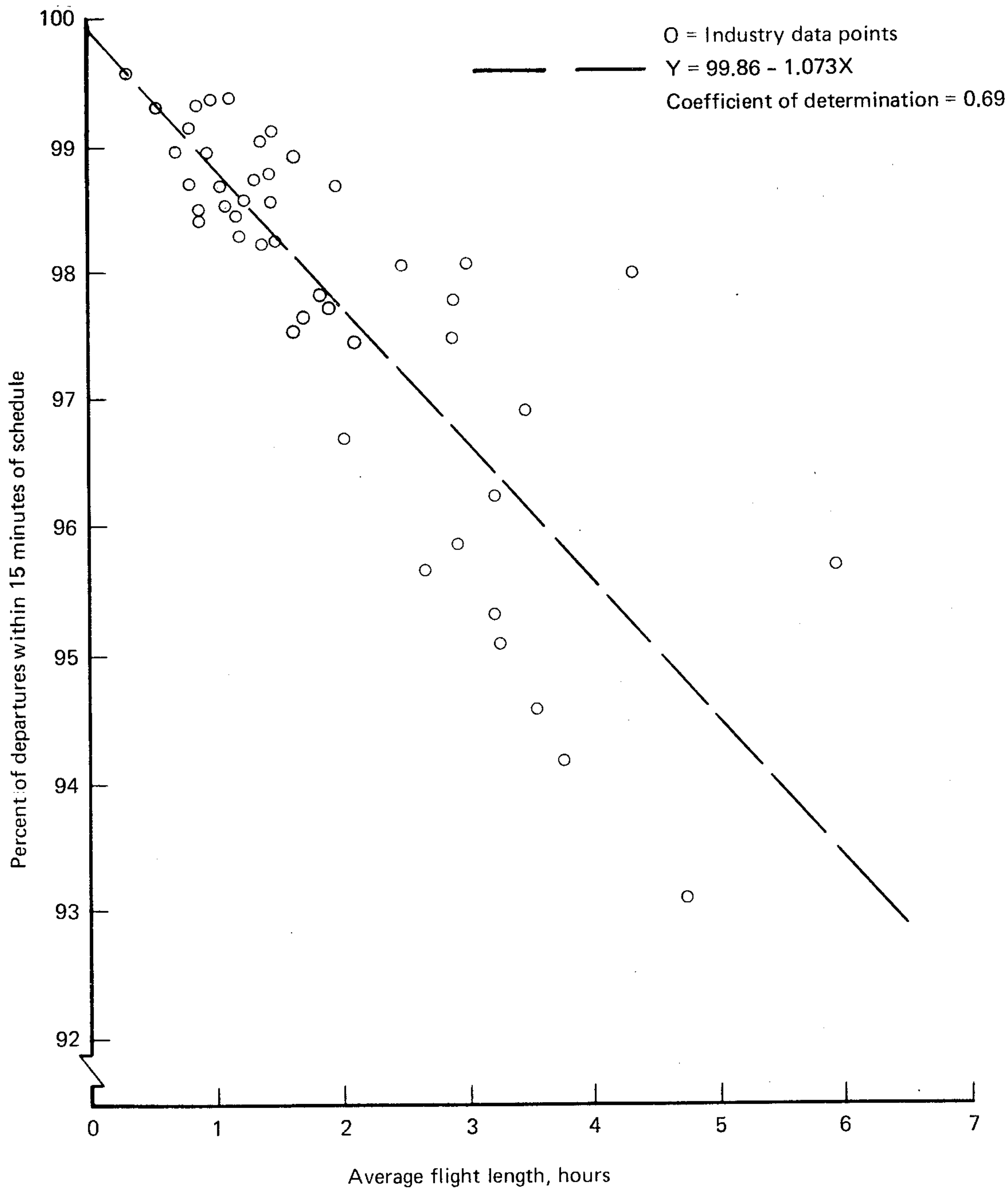


Figure 130.—Mechanical Dispatch Reliability (Y) (Delays Greater Than 15 Minutes) As a Function of Flight Length (X) For All U.S. Operators Boeing Fleets (1972) (Boeing Data)

Table 26.—Mechanical Delays and Cancellations Per 100 Departures (Y) As A Function of Various Parameters (X) for Each ATA System

ATA system	Relationship	X	Coefficient of determination
21 + 36	Y = X/(4.02X + 4.73)	AFLH X (kgs/min)X10^{-2}	0.73
29	Y = X/(1.29X + 5.85)	AFLH	0.56
32	Y = X/(-13.42X + 1057.70	VAP	0.75
38	Y = X/(-95.81X + 360.85)	AFLH	0.86
49	Y = -0.01 + 0.04	AFLA	0.97
52	Y = X/(-0.23X + 239.84)	$\sqrt{\text{SEATS X AFLH}}$	0.64
53	Y = X/(101.98 + 272.20)	AFLH	0.53
54	Y = X/(-57.12X + 409.24)	AFLH	0.73

No satisfactory relationships were established for ATA System:

22, 23, 24, 25, 26, 27, 28, 30, 31, 33, 34, 35, 55, 56, and 57.

kgs/min = Air conditioning system flow rate

AFLH = Average flight length, in hours

VAP = Approach speed, in meters per second

See table 9 for the ATA System description

Table 27.—Avoided Delays Per 100 Departures (Y) As A Function of Various Parameters (X) For Each ATA System

ATA system	Relationship	X	Coefficient of determination
21 + 36	Y = X/(-0.21X + 949.48)	AFLH	0.91
23	Y = X/(0.83X + 12.72)	AFLH	0.82
24	Y = X/(-0.5X + 6.71)	AFLH	0.89
25	Y = SEATS [X/(-3.14X + 15.25)]	AFLH	0.73
26	Y = X/(-4.54X + 20.41)	AFLH	0.69
28	Y = -0.22 + 0.32X	AFLH	0.96
29	Y = NHS [1/(65.50 - 17.45X)]	AFLH	0.74
31	Y = -0.04 + 0.02X	AFLH	0.57
33	Y = -0.26 + 0.04X	$\sqrt{\text{SEATS X AFLH}}$	0.72
34	Y = X/(-0.41X + 4.39)	AFLH	0.70
35	Y = X/(-115.13X + 452.70)	AFLH	0.81
49	Y = 0.21 + 0.39X	AFLH	0.93

No satisfactory relationships were established for ATA Systems:
22, 27, 30, 32, 52, 56.

No minimum equipment list dispatches recorded for ATA Systems:
55 and 57

AFLH = Average flight length in hours

SEATS = number of seats

See table 9 for the ATA System description

;

4.0 DELAY LENGTH

Delay length is a function of the scheduled ground time, the time taken to establish the need for corrective action, and the time taken to correct the problem. Separate analysis of the probability distributions for the above variables and relating them to design characteristics of the airplane was considered to be outside the scope of this study.

From Boeing data files, it was possible to construct, on the basis of one airline's data, an awareness of the length of a delay for 727-200 series aircraft as a function of the number of delays (fig. 131). In addition, delay length characteristic data for another airline operating similar equipment to American Airlines is included as table 28.

Table 28.—Percentage of Mechanical Delays (Y) Which Depart A Given Number of Minutes (X) After the Departure Time

Model	Relationship		Coefficient of determination
727	$Y = -4.727 + \frac{1675}{X}$	for $354 \geq X \geq 16$	.98
	$Y = 100$	for $X < 16$	
707	$Y = -1.22 + \frac{1626}{X}$	for $1332 \geq X \geq 16$	.98
	$Y = 100$	for $X < 16$	
747	$Y = 4.34 + \frac{1539}{X}$	for $1440 \geq X \geq 16$	.94
	$Y = 100$	for $X < 16$	
DC-10	$Y = -2.42 + \frac{1683}{X}$	for $694 \geq X \geq 16$	.98
	$Y = 100$	for $X < 16$	

The data used for table 28 were truncated for delays of less than 16 minutes, as the airline from which the data was derived considers any departure 16 minutes or less behind schedule as "on time."

The costs (1976 $) in table 29 are for the American Airlines fleet average flight length of 1.7 hours, and average mechanical delay rate of 2.4 per 100 departures. Shorter or longer flight lengths will result in different costs because of the flight length relationship noted in table 26. On the basis of the system cost percentages, the total cost for mechanical delays and cancellations represents approximately 4% of the total (airframe and engine) direct maintenance costs.

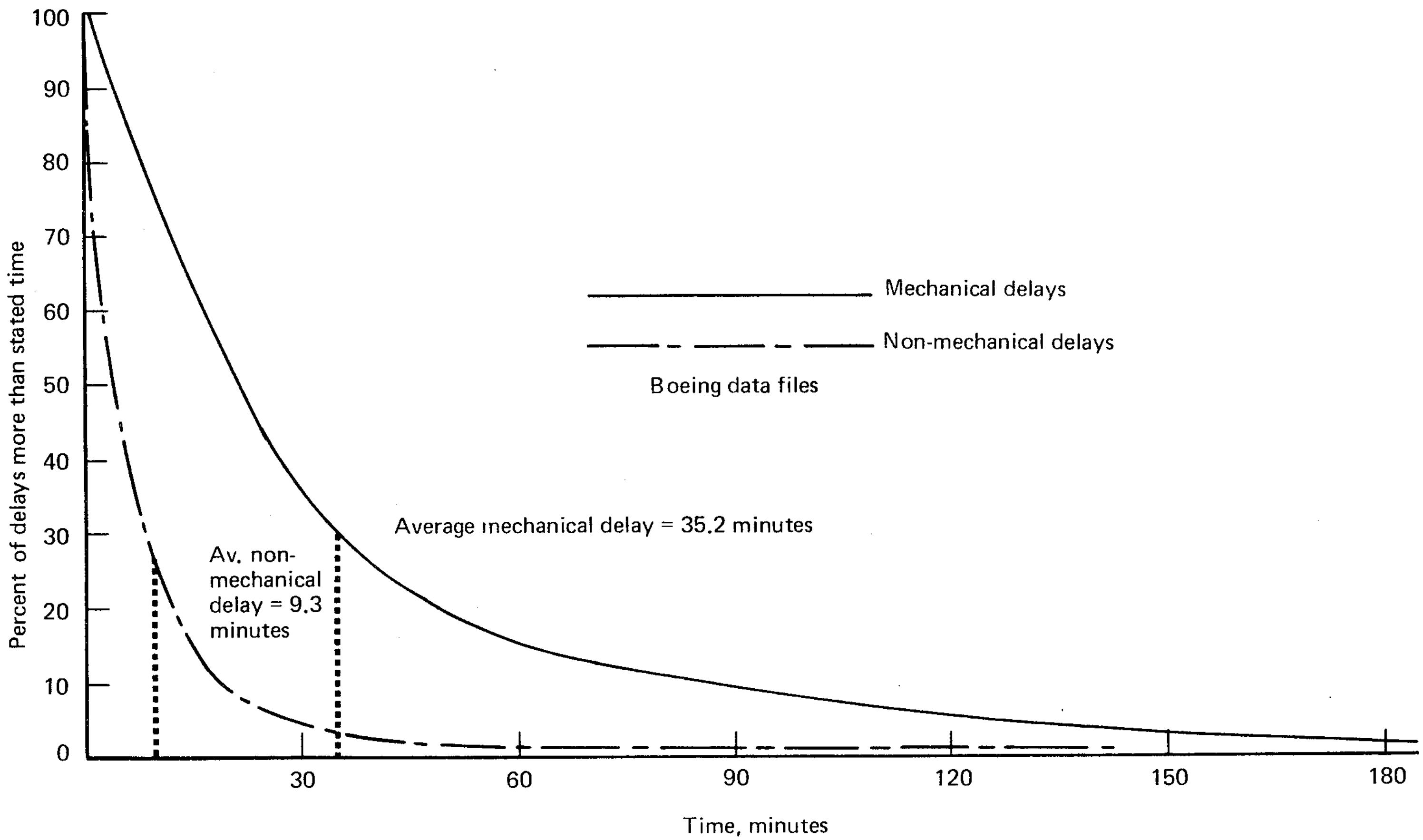


Figure 131.—Delay Length For a 727-200

Table 29.—Mechanical Delay and Cancellation Costs, 1976$ (American Airlines Fleet)

Average flight length

Rank	System	ATA	Cost $/ 100 dep	Cost $/ flight hour	Cost % system DMC
1	Landing gear	32	201.10	1.183	.74
2	Hydraulic	29	188.44	1.108	3.55
3	Flight controls	27	155.63	.915	1.74
4	Engine (basic)	72	91.97	.541	*
5	Navigation	34	86.11	.506	.75
6	Engine starting	80	59.77	.352	*
7	Air conditioning	21	56.57	.333	.74
8	Engine oil	79	51.80	.305	*
9	Fuel	28	48.77	.287	1.76
10	Fire protection	26	47.41	.279	3.48
11	Engine fuel and control	73	43.37	.255	*
12	Thrust reverser	78	42.10	.248	*
13	Electrical	24	39.82	.234	.69
14	Pneumatics	36	36.90	.217	2.37
15	Doors	52	34.71	.204	1.13
	Other		243.64	1.433	*
	Total		1428.11	8.400	

*Propulsion Systems Maintenance Cost Data not analyzed.

Total AA Direct Maintenance Costs for 1976 = $129.887 mil.

Total AA Fleet Flying Hours for 1976 = 658 358 hours.

Ave Fleet DMC Cost/Flight Hour = $\dfrac{\$129.887 \text{ mil.}}{658.358}$

= $\underline{\$197.29}$ per aircraft hour flown

Ave Mechanical Delay and Cancellation costs per flight hour (ref. table 29)

= $8.40

Mechanical Delay and Cancellation costs expressed as a percentage of Aircraft Direct Maintenance costs

$$= \frac{\$8.40}{197.29} \times 100 = \underline{4.26\%}$$

It can be seen from figures 124, 125, 126, and 131 that the average of all nonmechanical delays is considerably shorter than the average of all mechanical delays, and, in consequence, the model 727 average cost per nonmechanical delay is only $166 compared to a mechanical delay average cost of $596 for the American Airlines' fleet. Using $166 per delay, the data of table 24 can be converted into 1976 dollar costs.

Table 30.—Nonmechanical Delay Costs, 1976 Dollars (American Airlines Model 727)

Rank		Cost $/ 100 dep	Cost $/ flight hour*	Cost % DMC *
1	Late arrivals from another station	742	5.6	7.5
2	Passenger service	459	3.5	4.7
3	Late cargo and cabin service	399	3.0	4.0
4	Weather	238	1.8	2.4
5	Airplane late from hangars	184	1.4	1.9
6	Other	168	1.3	1.7
7	Ground Equipment	128	.9	1.2
8	Late crew and crew caused delays	37	.3	.4
9	Stores and parts shortages	14	.1	.1
	Total	2369	17.9	24.1

Note* Average 727 flight length = 1.323 hours

** American Airlines 1976 direct maintenance costs for the 727-200 airframe items was $74.29/flight hour.

The delay costs for the above nonmechanical delay categories are for an average 727 delay length of 9.3 minutes (see fig. 131) and represents an equivalent of 24.09% of the airframe direct maintenance costs, i.e., $\frac{\$17.9}{74.29} \times 100 = 24.09\%$.

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5.0 DELAY AND CANCELLATION COST PER FLIGHT HOUR

Delay and cancellation costs are not separately reported on the Civil Aeronautics Board Form 41. They are contained in objective accounts 23, 24, 25, 31, 57, 63, and 87 of reference 10. It is therefore difficult to check the validity of the delay and cancellation costs in this section and it is important to keep in mind how such costs are developed, namely:

a) Tangible costs per delay or per cancellation are based on the data presented in paragraph 3.2.

b) Historical delay and cancellation frequencies presented in paragraph 3.3 form the basis for assessing current costs and making predictions.

c) Delay length data of paragraph 3.5 are the basis of calculated delay and cancellation costs per flight hour.

Delay and cancellation costs per flight hour can be obtained from the expressions:

$$\text{Delay cost} = \frac{(\text{Delays/100 deps.}) \times (\text{delay length}) \times (\text{cost/delay/unit of time})}{\text{Average flight length} \times 100}$$

$$\text{Cancellation cost} = \frac{(\text{Cancellations/1000 ceps.}) \times (\text{cost/cancellation})}{\text{Average flight length} \times 1000}$$

In the above expressions, delay and cancellation costs are in units of dollars per flight hour and are compared for importance with direct maintenance cost in table 29. Details of the costs used to develop table 29 are provided in Attachment A and paragraph 3.5 and the systems have been ranked in terms of delay cost per 100 departures.

6.0 NEW DESIGN ANALYSIS

The relationships developed in the preceding sections can be used for assessing the cost of delays and cancellations in the following manner:

a) The assumption is made that operation and scheduling of the new airplane is similar to the airplanes analyzed.

b) Baseline delay and cancellation rates are established using the appropriate formulas of paragraph 3.4.

c) Baseline rates are adjusted by engineering judgment to account for differences between the new design and the existing airplanes used to develop the baseline rates.

The following provides an example of the application of the above technique to the TAC/Energy and CWB-E airplanes. Characteristics of the two airplanes are shown in table 31.

Table 31.—Airplane Design Characteristics

	TAC/Energy	CWB-E
Average flight length	2.50	2.50
Air conditioning capacity	159 kg/min	159 kg/min
Number of engine generators	4	3
Narrow or wide body	Wide	Wide
Maximum gross weight	115 300	147 200
Number of hydraulic systems	4	3
APU hours per flight hour	1.5	1.2
Number of seats	200	200

A review of the two airplanes for the purpose of this example shows that:

a) The CWB-E airplane is similar to other airplanes used in the data base, while the TAC/Energy airplane differs significantly in that it has a quadraplex hydraulic system, four generators and powered wheels.

b) Because of the powered wheels, failures normally discovered at departure from the gate may not be discovered until engine start-up at the end of the runway. The resultant increase in delay length is assumed to add twenty minutes to 25% of the mechanical delays. In reference 12 the powered wheels were assumed to be free of mechanical problems causing delays.

To simplify the example, TAC/Energy airplane features such as full time longitudinal stability augmentation and advanced environmental control have been excluded.

Table 32 shows the results of using the estimating relationship of table 26 and the airplane characteristics of table 31 as an illustration of the method of estimating delay and cancellation costs for the two concepts and accounting for the differences (a) and (b) above.

In table 32 the average event cost was based on the DC-10-10 for which delays in the category 0-29 minutes, 30-59 minutes and greater than 60 minutes are 44.4%, 29.5%, and 26.1% respectively, using the relationships of table 28. (Attachment C provides details of the method of calculating the delay and cancellation costs per occurrence.)

7.0 CONCLUSIONS AND RECOMMENDATIONS

a) While the tangible costs associated with mechanical delays and cancellations represent only 3 or 5% of the direct airframe maintenance cost, the cost of nonmechanical delays is high (equivalent to approximately 25% of direct airframe maintenance costs). Further work to establish a more exact cost of a delay, and to investigate the payoff for eliminating departure delays due to late arrivals, servicing, and weather is recommended.

b) Judgment is required in applying most of the relationships developed herein to new design technology. Considerably more work would be necessary to develop expressions in terms of design parameters which could be safely extrapolated. In addition, it would be desirable to confirm the various hypotheses made (physical relationships implied by the empirically derived equations) by examination of detailed delay records.

Table 32.—*TAC/Energy and CWB-E Delay and Cancellation Cost*

ATA system	System description	Delays and cancellations per 100 departures		Delay and cancellation cost per system (1976 $ per 100 departures)		Cost per system (1976 $ per flight hour)		Remarks
		TAC/Energy	CWB-E	TAC/Energy	CWB-E	TAC/Energy	CWB-E	
21 + 36	Air conditioning plus pneumatics	.2479	.2479	210	180	.84	.72	
22	Autopilot	–	–	–	–	–	–	No parametric estimating method
23	Communications	.0489	.0489	42	36	.17	.14	
24	Electrical power	–	–	–	–	–	–	No parametric estimating method
25	Furnishings	.0842	.0842	71	61	.28	.24	
26	Fire detection	–	–	–	–	–	–	No parametric estimating method
27	Flight controls	–	–	–	–	–	–	No parametric estimating method
28	Fuel	.1074	.0991	91	72	.36	.28	
29	Hydraulics	.3675	.2756	312	200	1.25	.80	TAC/Energy = $\frac{4}{3}$ x CWB-E
30	Ice and rain	–	–	–	–	–	–	No parametric estimating method
31	Instruments	–	–	–	–	–	–	No parametric estimating method
32	Landing gear	.5405	.3445	459	250	1.84	1.00	
33	Lights	–	–	–	–	–	–	No parametric estimating method
34	Navigation	–	–	–	–	–	–	No parametric estimating method
35	Oxygen	–	–	–	–	–	–	No parametric estimating method
38	Water waste	.0206	.0206	17	15	.07	.06	
49	Auxiliary power	.0971	.0971	82	71	.33	.28	
52	Doors	.0952	.0952	81	69	.32	.28	
53	Fuselage	.0047	.0047	4	3	.02	.01	
54	Nacelles	.0094	.0094	8	7	.03	.03	
55	Stabilizers	–	–	–	–	–	–	No parametric estimating method
56	Windows	–	–	–	–	–	–	
57	Wings	–	–	–	–	–	–	
	Totals			1377	964	5.51	3.84	

ATTACHMENT A

Attachment A provides details of the frequency and cost of mechanical delays and cancellations for the combined American Airlines fleet. The delay and cancellation rate data for different delay length classes and different airplane models is provided on pages 249 through 252 for the year of 1974.

ATA system [1]	0-29 min Delays/ 100 dep [2]	Cost/ delay [3]	Cost/ 100 dep	30-60 min Delays/ 100 dep	Cost/ delay [2]	Cost/ 100 dep [3]	> 60 min Delays/ 100 dep	Cost/ delay [2]	Cost/ 100 dep [3]
			Delay Time (Avg)						
21	.0458	x 122.66 =	5.62	.0261	x 310.14 =	8.09	.0253	x 1380.62 =	34.93
22	.0314		3.85	.0136		4.22	.0114		15.74
23	.0272		3.34	.0086		2.67	.0039		5.38
24	.0552		6.77	.0250		7.75	.0161		22.23
25	.0589		7.22	.0155		4.81	.0044		6.07
26	.0197		2.42	.0150		4.65	.0219		30.24
27	.0536		6.57	.0530		16.44	.0689		95.12
28	.0677		8.30	.0217		6.73	.0183		25.27
29	.0738		9.05	.0630		19.54	.0958		132.26
30	.0153		1.88	.0136		4.22	.0100		13.81
31	.0205		2.51	.0039		1.21	.0028		3.87
32	.1355		16.62	.1011		31.36	.0891		123.01
33	.0333		4.08	.0105		3.26	.0050		6.90
34	.1355		16.62	.0489		15.17	.0336		46.39
35	.0275		3.37	.0058		1.80	.0031		4.28
36	.0111		1.36	.0175		5.43	.0175		24.16
38	.0078		.96	.0044		1.36	.0014		1.93
49	.0283		3.47	.0036		1.12	.0028		3.87
52	.0558		6.84	.0186		5.77	.0117		16.15
53	.0033		.40	.0011		.34	.0008		1.10
54	.0047		.58	.0008		.25	.0011		1.52
55	.0008		.10	.0008		.25	.0		0
56	.0083		1.02	.0072		2.23	.0086		11.87
57	.0050		.61	.0022		.68	.0042		5.80
71	.0058		.71	.0019		.59	.0025		3.45
72	.0111		1.36	.0136		4.22	.0358		49.43
73	.0303		3.72	.0142		4.40	.0194		26.78
74	.0039		.48	.0064		1.98	.0092		12.70
75	.0197		2.42	.0147		4.56	.0155		21.40
76	.0036		.44	.0028		.87	.0031		4.28
77	.0078		.96	.0053		1.64	.0078		10.77
78	.0464		5.69	.0236		7.32	.0178		24.58
79	.0319		3.91	.0283		8.78	.0214		29.55
80	.0453		5.56	.0278		8.62	.0308		42.52
00	.0153	x 122.66 =	1.88	.0061	x 310.14 =	1.89	.0025	x 1380.62 =	3.45
Total	1.147		140.69	.626		194.22	.623		860.91

[1] See section 3.0 (Nomenclature) for code descriptions

[2] American Airlines estimate (1976 $)

[3] 1976 $

ATA system [1]	Cancellations/ 100 dep		Cost per cancellation [2]		Cost per 100 dep [3]
21	.0044	x	1803	=	7.93
22	.0011				1.98
23	0				0
24	.0017				3.07
25	.0006				1.08
26	.0056				10.10
27	.0208				37.50
28	.0047				8.47
29	.0153				27.59
30	0				0
31	0				0
32	.0167				30.11
33	0				0
34	.0044				7.93
35	.0006				1.08
36	.0033				5.95
38	0				0
49	.0003				.54
52	.0033				5.95
53	0				0
54	0				0
55	0				0
56	.0061				10.99
57	0				0
71	0				0
72	.0205				36.96
73	.0047				8.47
74	.0006				1.08
75	.0033				5.95
76	0				0
77	.0014				2.52
78	.0025				4.51
79	.0053				9.56
80	.0017	x	1803	=	3.07
Total	.129				232.39

[1] See section 3.0 (Nomenclature) for code descriptions

[2] American Airlines estimate (1976 $)

[3] 1976 $

ATA	707PSGR	727-100	727-200	747	707CF	DC-10	AVE	RANK
HRS	242Ø37.	145856.	117Ø63.	21146.	29563.	56342.		
DPTS	12Ø689.	111733.	84964.	6Ø78.	1Ø891.	25845.		

1974 NO. 6-29 MIN DELAYS PER 1ØØ DEPARTURES, 3-8-77

ATA	707PSGR	727-100	727-200	747	707CF	DC-10	AVE	RANK
21	0.0729	0.0260	0.0459	0.0329	0.0	0.0271	0.0458	10
22	0.0431	0.0170	0.0282	0.0329	0.0092	0.0580	0.0314	14
23	0.0340	0.0206	0.0235	0.0659	0.0	0.0387	0.0272	18
24	0.0762	0.0474	0.0400	0.0494	0.0092	0.0619	0.0552	7
25	0.0646	0.0304	0.0388	0.1318	0.0092	0.2244	0.0589	5
26	0.0232	0.0179	0.0177	0.0494	0.0092	0.0155	0.0197	20
27	0.0530	0.0635	0.0530	0.0329	0.0275	0.0310	0.0536	8
28	0.0514	0.0564	0.1106	0.0329	0.0092	0.0851	0.0677	4
29	0.1085	0.0456	0.0612	0.0824	0.0367	0.0890	0.0738	3
30	0.0133	0.0116	0.0247	0.0494	0.0	0.0077	0.0153	22
31	0.0323	0.0143	0.0165	0.0	0.0092	0.0155	0.0205	19
32	0.1848	0.1074	0.1153	0.1153	0.0918	0.1161	0.1355	1
33	0.0331	0.0331	0.0341	0.0165	0.0092	0.0464	0.0333	12
34	0.1757	0.1128	0.1071	0.0988	0.0826	0.1702	0.1355	1
35	0.0398	0.0143	0.0294	0.0659	0.0092	0.0193	0.0275	17
36	0.0008	0.0081	0.0188	0.0494	0.0	0.0426	0.0111	24
38	0.0157	0.0036	0.0047	0.0	0.0	0.0039	0.0078	27
49	0.0	0.0358	0.0377	0.1483	0.0	0.0813	0.0283	16
52	0.0613	0.0277	0.0306	0.1318	0.0	0.2399	0.0558	6
53	0.0050	0.0027	0.0035	0.0	0.0	0.0	0.0033	34
54	0.0075	0.0036	0.0035	0.0	0.0	0.0039	0.0047	31
55	0.0008	0.0009	0.0012	0.0	0.0	0.0	0.0008	35
56	0.0149	0.0081	0.0035	0.0	0.0	0.0	0.0083	26
57	0.0091	0.0009	0.0059	0.0	0.0	0.0039	0.0050	30
71	0.0050	0.0009	0.0035	0.0	0.0	0.0426	0.0058	29
72	0.0191	0.0063	0.0106	0.0	0.0	0.0039	0.0111	24
73	0.0439	0.0224	0.0282	0.0165	0.0	0.0232	0.0303	15
74	0.0050	0.0072	0.0	0.0	0.0	0.0	0.0039	32
75	0.0232	0.0152	0.0200	0.0	0.0184	0.0271	0.0197	20
76	0.0075	0.0009	0.0012	0.0165	0.0	0.0039	0.0036	33
77	0.0075	0.0063	0.0082	0.0	0.0	0.0193	0.0078	27
78	0.0696	0.0206	0.0282	0.0329	0.0184	0.1238	0.0464	9
79	0.0348	0.0322	0.0353	0.0	0.0184	0.0193	0.0319	13
80	0.0489	0.0492	0.0447	0.0494	0.0092	0.0271	0.0453	11
00	0.0199	0.0107	0.0094	0.0165	0.0	0.0387	0.0153	22
TT	1.405	0.882	1.045	1.318	0.376	1.710	1.147	

ATA	707PSGR	727-100	727-200	747	707CF	DC-10	AVE	RANK
HRS	242037.	145856.	117063	21146.	29563.	56342.		
DPTS	120689.	111733.	84964.	6078.	10891	25845.		

1974 NO. 30-59 MIN DELAYS PER 100 DEPARTURES, 3-8-77

21	0.0365	0.0188	0.0247	0.0494	0.0367	0.0039	0.0261	7
22	0.0199	0.0072	0.0153	0.0	0.0275	0.0039	0.0136	17
23	0.0141	0.0054	0.0059	0.0165	0.0092	0.0039	0.0086	21
24	0.0323	0.0233	0.0153	0.0329	0.0184	0.0310	0.0250	8
25	0.0191	0.0107	0.0059	0.0659	0.0275	0.0348	0.0155	13
26	0.0083	0.0197	0.0188	0.0494	0.0	0.0116	0.0150	14
27	0.0431	0.0519	0.0518	0.1647	0.0184	0.0967	0.0530	3
28	0.0240	0.0170	0.0224	0.0165	0.0275	0.0271	0.0217	10
29	0.0928	0.0430	0.0494	0.0494	0.0551	0.0619	0.0630	2
30	0.0149	0.0161	0.0141	0.0165	0.0	0.0	0.0136	17
31	0.0075	0.0018	0.0024	0.0	0.0092	0.0	0.0039	28
32	0.1351	0.0609	0.0741	0.1977	0.1469	0.1625	0.1011	1
33	0.0116	0.0089	0.0094	0.0329	0.0092	0.0116	0.0105	20
34	0.0563	0.0367	0.0282	0.1153	0.1561	0.0735	0.0489	4
35	0.0058	0.0054	0.0082	0.0	0.0	0.0039	0.0058	25
36	0.0008	0.0188	0.0212	0.0494	0.0	0.0774	0.0175	12
38	0.0066	0.0027	0.0	0.0329	0.0	0.0116	0.0044	27
49	0.0	0.0072	0.0035	0.0	0.0	0.0077	0.0036	29
52	0.0149	0.0143	0.0106	0.0329	0.0459	0.0658	0.0186	11
53	0.0017	0.0	0.0	0.0	0.0092	0.0039	0.0011	33
54	0.0025	0.0	0.0	0.0	0.0	0.0	0.0008	34
55	0.0008	0.0009	0.0012	0.0	0.0	0.0	0.0008	34
56	0.0083	0.0089	0.0024	0.0	0.0275	0.0039	0.0072	22
57	0.0033	0.0009	0.0024	0.0	0.0092	0.0	0.0022	31
71	0.0017	0.0009	0.0	0.0	0.0	0.0155	0.0019	32
72	0.0133	0.0116	0.0106	0.0	0.0092	0.0387	0.0136	17
73	0.0199	0.0098	0.0071	0.0329	0.0184	0.0232	0.0142	16
74	0.0008	0.0116	0.0059	0.0329	0.0092	0.0039	0.0064	23
75	0.0215	0.0063	0.0129	0.0165	0.0275	0.0193	0.0147	15
76	0.0050	0.0018	0.0	0.0165	0.0	0.0039	0.0028	30
77	0.0033	0.0072	0.0035	0.0	0.0	0.0155	0.0053	26
78	0.0174	0.0161	0.0177	0.0494	0.0	0.1083	0.0236	9
79	0.0282	0.0277	0.0330	0.0659	0.0275	0.0077	0.0283	5
80	0.0456	0.0188	0.0129	0.0165	0.0551	0.0232	0.0278	6
00	0.0025	0.0063	0.0059	0.0	0.0275	0.0155	0.0061	24
TT	0.719	0.499	0.497	1.153	0.808	0.971	0.626	

ATA	7Ø7PSGR	727-1ØØ	727-2ØØ	747	7Ø7CF	DC-1Ø	AVE	RANK
HRS	242Ø37.	145856.	117Ø63.	21146.	29563.	56342.		
DPTS	12Ø689.	111733.	84964.	6Ø78.	1Ø891.	25845.		

1974 NO. DELAYS 6Ø MIN AND GREATER PER 1ØØ DEPARTURES, 3-8-77

21	Ø.Ø439	Ø.Ø125	Ø.ØØ94	Ø.Ø165	Ø.Ø826	Ø.Ø232	Ø.Ø253	7
22	Ø.Ø133	Ø.ØØ81	Ø.Ø141	Ø.Ø165	Ø.Ø184	Ø.ØØ39	Ø.Ø114	17
23	Ø.ØØ66	Ø.ØØ27	Ø.ØØ12	Ø.Ø	Ø.ØØ92	Ø.ØØ39	Ø.ØØ39	25
24	Ø.Ø199	Ø.ØØ72	Ø.Ø1Ø6	Ø.Ø494	Ø.ØØ92	Ø.Ø5Ø3	Ø.Ø161	14
25	Ø.ØØ25	Ø.ØØØ9	Ø.ØØ47	Ø.Ø329	Ø.ØØ92	Ø.Ø193	Ø.ØØ44	23
26	Ø.Ø124	Ø.Ø188	Ø.Ø282	Ø.Ø494	Ø.Ø367	Ø.Ø464	Ø.Ø219	8
27	Ø.Ø638	Ø.Ø814	Ø.Ø424	Ø.1318	Ø.Ø918	Ø.1ØØ6	Ø.Ø689	3
28	Ø.Ø141	Ø.Ø134	Ø.Ø118	Ø.Ø	Ø.Ø643	Ø.Ø658	Ø.Ø183	11
29	Ø.111Ø	Ø.Ø716	Ø.Ø694	Ø.1483	Ø.1745	Ø.17Ø2	Ø.Ø958	1
3Ø	Ø.ØØ91	Ø.ØØ54	Ø.Ø153	Ø.Ø494	Ø.Ø184	Ø.ØØ39	Ø.Ø1ØØ	18
31	Ø.ØØ41	Ø.ØØ18	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø116	Ø.ØØ28	28
32	Ø.1177	Ø.Ø555	Ø.Ø671	Ø.1153	Ø.Ø918	Ø.1664	Ø.Ø891	2
33	Ø.ØØ58	Ø.ØØ45	Ø.ØØ47	Ø.Ø	Ø.Ø	Ø.ØØ77	Ø.ØØ5Ø	22
34	Ø.Ø456	Ø.Ø251	Ø.Ø224	Ø.Ø	Ø.Ø367	Ø.Ø58Ø	Ø.Ø336	5
35	Ø.ØØ25	Ø.ØØ36	Ø.ØØ12	Ø.Ø	Ø.ØØ92	Ø.ØØ77	Ø.ØØ31	26
36	Ø.ØØ17	Ø.Ø134	Ø.Ø294	Ø.Ø165	Ø.Ø	Ø.Ø774	Ø.Ø175	13
38	Ø.ØØ25	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.ØØ77	Ø.ØØ14	32
49	Ø.Ø	Ø.ØØ54	Ø.ØØ24	Ø.Ø165	Ø.Ø	Ø.ØØ39	Ø.ØØ28	28
52	Ø.ØØ91	Ø.Ø1Ø7	Ø.ØØ47	Ø.Ø165	Ø.Ø275	Ø.Ø426	Ø.Ø117	16
53	Ø.ØØ17	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.ØØ39	Ø.ØØØ8	34
54	Ø.ØØ17	Ø.ØØØ9	Ø.Ø	Ø.Ø165	Ø.Ø	Ø.Ø	Ø.ØØ11	33
55	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	35
56	Ø.Ø1Ø8	Ø.ØØ54	Ø.Ø1Ø6	Ø.Ø165	Ø.Ø	Ø.ØØ77	Ø.ØØ86	2Ø
57	Ø.ØØ25	Ø.ØØ18	Ø.ØØ35	Ø.Ø	Ø.Ø643	Ø.Ø	Ø.ØØ42	24
71	Ø.ØØØ8	Ø.ØØ18	Ø.ØØ35	Ø.Ø	Ø.Ø	Ø.Ø116	Ø.ØØ25	3Ø
72	Ø.Ø298	Ø.Ø242	Ø.Ø271	Ø.1318	Ø.Ø459	Ø.1161	Ø.Ø358	4
73	Ø.Ø257	Ø.Ø116	Ø.Ø165	Ø.Ø165	Ø.Ø275	Ø.Ø31Ø	Ø.Ø194	1Ø
74	Ø.ØØ5Ø	Ø.Ø161	Ø.ØØ82	Ø.Ø165	Ø.Ø	Ø.ØØ39	Ø.ØØ92	19
75	Ø.Ø265	Ø.ØØ63	Ø.Ø165	Ø.Ø	Ø.Ø275	Ø.Ø	Ø.Ø155	15
76	Ø.ØØ17	Ø.ØØ27	Ø.ØØ12	Ø.Ø165	Ø.Ø	Ø.Ø155	Ø.ØØ31	26
77	Ø.ØØ5Ø	Ø.ØØ72	Ø.ØØ71	Ø.Ø	Ø.Ø	Ø.Ø31Ø	Ø.ØØ78	21
78	Ø.ØØ75	Ø.ØØ98	Ø.Ø188	Ø.Ø824	Ø.Ø	Ø.Ø89Ø	Ø.Ø178	12
79	Ø.Ø249	Ø.Ø188	Ø.Ø247	Ø.Ø329	Ø.ØØ92	Ø.ØØ77	Ø.Ø214	9
8Ø	Ø.Ø273	Ø.Ø242	Ø.Ø224	Ø.Ø659	Ø.Ø459	Ø.Ø89Ø	Ø.Ø3Ø8	6
ØØ	Ø.ØØ17	Ø.ØØ27	Ø.ØØ24	Ø.Ø	Ø.ØØ92	Ø.ØØ39	Ø.ØØ25	3Ø
TT	Ø.658	Ø.475	Ø.5Ø1	1.Ø54	Ø.9Ø9	1.281	Ø.623	

ATA	707PSGR	727-100	727-200	747	707CF	DC-10	AVE	RANK
HRS	242037.	145856.	117063.	21146.	29563.	56342.		
DPTS	120689.	111733.	84964.	6078.	10891.	25845.		

1974 CANCELLATIONS PER 100 DEPARTURES, 8-22-77

21	0.0116	0.0	0.0	0.0	0.0	0.0077	0.0044	10
22	0.0008	0.0009	0.0012	0.0	0.0	0.0039	0.0011	19
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24
24	0.0033	0.0009	0.0	0.0	0.0	0.0039	0.0017	16
25	0.0	0.0	0.0024	0.0	0.0	0.0	0.0006	20
26	0.0025	0.0089	0.0082	0.0	0.0	0.0	0.0056	6
27	0.0083	0.0331	0.0294	0.0	0.0	0.0116	0.0208	1
28	0.0066	0.0018	0.0012	0.0	0.0367	0.0077	0.0047	8
29	0.0149	0.0107	0.0177	0.0165	0.0	0.0348	0.0153	4
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24
32	0.0207	0.0134	0.0141	0.0	0.0	0.0310	0.0167	3
33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24
34	0.0075	0.0054	0.0	0.0165	0.0	0.0	0.0044	10
35	0.0008	0.0	0.0012	0.0	0.0	0.0	0.0006	20
36	0.0	0.0054	0.0035	0.0165	0.0	0.0077	0.0033	12
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24
49	0.0	0.0	0.0	0.0	0.0	0.0039	0.0003	23
52	0.0058	0.0	0.0047	0.0	0.0	0.0039	0.0033	12
53	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24
54	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24
55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24
56	0.0108	0.0081	0.0	0.0	0.0	0.0	0.0061	5
57	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24
71	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24
72	0.0182	0.0170	0.0200	0.0329	0.0	0.0542	0.0205	2
73	0.0033	0.0036	0.0012	0.0	0.0	0.0310	0.0047	8
74	0.0	0.0018	0.0	0.0	0.0	0.0	0.0006	20
75	0.0066	0.0	0.0047	0.0	0.0	0.0	0.0033	12
76	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24
77	0.0	0.0018	0.0	0.0	0.0	0.0116	0.0014	18
78	0.0	0.0027	0.0	0.0	0.0	0.0232	0.0025	15
79	0.0066	0.0072	0.0035	0.0	0.0	0.0	0.0053	7
80	0.0	0.0018	0.0035	0.0	0.0	0.0039	0.0017	16
00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24
TT	0.128	0.124	0.117	0.082	0.037	0.240	0.129	

ATTACHMENT B

The following discussion contains brief comments on the results of linear regression using mechanical delay and cancellations per 100 departures as the dependent variable.

The classification of the strength of correlation in terms of Coefficient of Determination into categories such as low, moderate, or high, requires the exercise of a certain degree of judgment. Since the resulting coefficients are stated in most instances, the reader can apply his own individual judgment. The following ranges were used in this discussion:

Description	Coefficient of Determination
High	.71 – 1.0
Moderate	.60 – .70
Low	<.60

Another consideration in applying these relationships is that care should be taken when exceeding the values of the range of the data used in the regression problems. The following list provides the values used in regressing mechanical delay and cancellation rates:

Parameter	Range	Units
Average flight length	1.33 – 3.33	Hours
Number of generators	3-5	Generators
Air conditioning flow rate	77 – 281	kg/min
Fuel capacity	24 600 – 144 800	kilograms
Velocity of approach	59.7 – 67.7	meters per sec.
Number of seats	103 – 423	Seats

ATA 21 + 36: Air Conditioning and Pneumatics

Delay and cancellation rate for the combination of air conditioning system and pneumatics shows a good coefficient (.73) using the product of flight length and airplane size as measured by air conditioning system capacity in kg/min of airflow. However, the two factors are not independent since airflow is a function of fuselage size and number of seats and the latter is correlated with flight length. It therefore can not be assumed that the relationship provided holds for a short range 747 or DC-10 or for small long-range standard body airplanes.

ATA 22: Auto Flight

The autopilot system delay and cancellation rates did not correlate well with any of the parameters tried, one parameter being the number of major line replaceable units. The combined delay plus minimum equipment list prevented delay rates were about double on the wide body airplanes compared to the standard body airplanes, probably as a result of higher levels of complexity. However, complexity is not always related to the number of line replaceable units and is difficult to model at the system level. Further study at the subsystem level might yield useful parameters.

ATA 23: Communications

The delay and cancellation rates have a low coefficient (.42) with flight length as the independent variable. A detailed analysis of subsystems should result in improved correlation using individual subsystem parameters instead of the total communications system as the independent variable. Another consideration would be average age of subsystem equipment being utilized, since new electronic systems and high-time systems should tend to have more problems.

ATA 24: Electrical Power

Electrical Power System delay and cancellation rate has an extremely low coefficient (.04) when using flight length. There was a slight improvement when the product of number of generators and flight length was introduced but the coefficient (.14) was still insignificant. Further study of the nature of subsystem failures might lead to more useful parameters.

ATA 25: Equipment and Furnishing

A low coefficient (.46) exists between average flight length and equipment and furnishing. This relationship could be rationalized on the basis that utilization of such furnishings as galleys and lavatories increases as the flight length increases. When the product of average flight length and number of seats was used as the independent variable, the coefficient (.43) was slightly reduced.

ATA 26: Fire Protection

Fire Protection system delay and cancellation rates did not yield a significant coefficient (.20) with flight length and the resulting relationship cannot be used for extrapolation to other airplanes. A relatively high coefficient (.80) resulted, when the reciprocal of number of years of airline revenue service for each model airplane was introduced as the independent variable. The newer model airplanes (DC-10-10) showed a higher delay-cancellation rate than the older ones (707's).

ATA 28: Fuel

The fuel system delay and cancellation rates yielded a poor coefficient (.25) when related to flight length and take-off gross weight. The coefficient (.47) was improved by using the product of average flight length and fuel capacity in pounds as the independent variable. A detailed analysis of failures by subsystem components could possibly reveal useful correlation parameters. This relationship using flight length as the independent variable should not be extrapolated to other airplanes.

ATA 29: Hydraulics

The delay and cancellation rates for hydraulics show a low coefficient (.56) to flight length. When the number of hydraulic systems were introduced as an independent variable, the correlation (.05) became negligible. Further investigation into maintenance records by subsystems could result in improved correlation parameters. This relationship could be extended to other airplane models.

ATA 31: Instruments

Instruments system delay and cancellation rates result in a low coefficient (.37) when compared to flight length. This low coefficient could indicate that electronic failures associated with recorders, computers, and central warning systems occur randomly and are not dependent upon variance in flight length.

ATA 32: Landing Gear

Landing gear delay and cancellation rates were found to have a significant coefficient (.75) by regressing against landing approach speed (VAP). When using flight time as the independent variable, a moderate coefficient (.58) resulted. The relationship using landing approach speed could be extrapolated to other airplanes.

ATA 33: Lights

Delays and cancellations exhibit a moderate coefficient (.56), when regressed with the square root of the product of flight length and number of seats. This relationship would indicate that extended usage on longer flights results in increased delay rates. A poor coefficient (.11) exists when using average flight length as the only independent variable.

ATA 34: Navigation

Delay and cancellation rates for the navigation system did not result in a useful coefficient (.08) with flight length. The failures associated with navigation instruments and electronic equipment could be analyzed using maintenance records of subsystem components. Since this system ranks among the top five systems causing delays and cancellations, further detailed analysis is needed.

ATA 35: Oxygen

Delays and cancellations were tested for correlation with flight length and number of seats. No significant coefficient could be established for this relationship using flight length and number of seats. Analysis of the nature of failures and servicing problems could yield meaningful results.

ATA 38: Water/Waste

Water and waste system delay and cancellation rates show a high coefficient (.86) when using flight length. This could be due to the higher usage of these systems on longer flights. The relationship could be extrapolated to other airplanes.

ATA 49: Auxiliary Power Unit

Auxiliary power unit system delay and cancellation rates show a high coefficient with both flight length (.97) and hours running time per flight (.95). These relationships could be extrapolated to other airplanes.

ATA 52: Doors

The delay and cancellation rates for doors have a moderate coefficient (.64) using the square root of the product of flight length and number of seats. Airplane size, which is reflected in number of seats, has an influence on the number of doors and door components involved. This relationship could be applied to other model airplanes if the ratio of seats to doors remains nearly constant.

ATA 53: Fuselage

The fuselage delay and cancellation rates correlated poorly (.53) to flight length. This would indicate that fuselage maintenance problems are not influenced by variance in flight length but are more randomly distributed. The product of flight length and takeoff gross weight also resulted in a low coefficient (.53). This relationship should not be extrapolated to other airplanes.

ATA 54: Nacelles and Pylons

The delay and cancellation rates for this system show a moderately high (.73) coefficient to flight length. This could indicate that the maintenance problems of this system are associated with the flight environment of airloads, vibration and temperature extremes. The influence of these factors increase with time in flight. The relationship derived for this system could be extrapolated to other airplanes.

ATA 27: Flight Controls; 30: Ice and Rain Protection; 55: Stabilizers; 56: Windows; 57: Wings

No satisfactory correlation parameters could be found. Further study at the subsystem level is recommended.

ATTACHMENT C

This attachment provides details of the method used to derive an average event cost for use in the example of section 6.0.

1) Cost per delay and per cancellation were selected from tables 21 and 22 for a DC-10-10 as the nearest equivalent airplane to the CWB-E and TAC/Energy concepts.

2) Table 28 was used to determine the percentage of delays in time intervals corresponding to table 21 and the assumption made that for the TAC/Energy airplane with powered wheels, 25% of the delays in the 16-29 and 30-59 categories would move into the next category as follows:

Delay category (minutes)	Percentage of delays DC-10/CWB-E	TAC/Energy
16-29	44.4	33.3
30-59	29.5	33.2
60	26.1	33.5

3) Using the percentage of delays above and cost of delays from table 21 an average delay cost was calculated:

$$\text{Average cost/delay (CWB-E)} = \frac{44.4 \times 170 + 29.5 \times 440 + 26.1 \times 1760}{100}$$

$$= \$665 \text{ (1976 \$)}$$

$$\text{Average cost /delay (TAC/Energy)} = \frac{33.3 \times 170 + 33.2 \times 440 + 33.5 \times 1760}{100}$$

$$= \$792 \text{ (1976 \$)}$$

4) Using delay rate to cancellation rate ratio for American Airlines DC-10-10 of 25.5 and a cancellation cost of \$2300 from table 23, an average event cost can be calculated:

$$\text{Average cost/event (CWB-E)} = \frac{25.5 \times 665 + 1 \times 2300}{26.5}$$

$$= \$727 \text{ (1976 \$)}$$

$$\text{Average cost/event (TAC/Energy)} = \frac{25.5 \times 792 + 1 \times 2300}{26.5}$$

$$= \$849 \text{ (1976 \$)}$$

ATTACHMENT D
DISTRIBUTION OF COMPONENT DCN EXPENSES
CALENDAR YEAR 1974

727 Aircraft Component	% of sum of total
ATA 21	
PRESSURIZATION CONTROL	13.34
AIR CYCLE SYS–GENERAL	13.79
CONTROLLER, WATER SEPARATOR TEMP ANTICE	3.94
RELAY, ACY SYS	3.94
SEPARATOR, AIR CONDITIONING AIR CYCLE SYS WATER	3.94
THERMOSTAT, WATER SEPARATOR	5.91
VALVE, ACY SYS PACK SHUT DOWN	7.88
WIRING, ENG STARTING	7.88
CABLE, ACY RAMAIR DOOR CONTROL	3.94
FAN	3.94
OTHER	31.50
ATA 22	
SERVO, AUTO PILOT STABILIZER TRIM CONT	11.25
VALVE, AUTO PILOT ELEV XFER	16.88
VALVE, AUTO PILOT YAW DAMPER ACTUATION XFER	38.10
OTHER	33.77
ATA 23	
SWITCH, FLIGHT INTERPHONE PUSH-TO-TEST	33.33
OTHER	66.67
ATA 24	
DRIVE, CONSTANT SPEED (CSD)	8.69
AC GENERATING–GENERAL	8.69
AC GENERATION CONTROL–GENERAL	8.69
PANEL, AC GENERATION CONTROL	17.39
WIRING, APU AC GENERATION FEEDER	13.04
INDICATOR, AC GENERATION INDN VM	8.69
BATTERY, DC, NICAD	8.69
OTHER	26.12

ATA 25

SEAT, PILOT AND COPLT	15.38
LAVATORY GENERAL	15.38
SLIDE, PASSENGER CABIN EMERGENCY ESCAPE	23.08
OTHER	46.16

ATA 26

CONNECTOR	8.07
CONNECTOR, FIRE/SMOKE DUCTING	12.11
ENG FIRE DETECTION–GENERAL	8.07
CONNECTOR, ENG FIRE DETECTOR	12.11
SENSOR, ENG FIRE DETECTION	55.59
OTHER	4.05

ATA 27

FLIGHT CONTROL–GENERAL	4.28
COMPUTER ELEVATOR FEEL	1.48
FTG, ELEVATOR SYS HYD	2.22
LINE, ELEVATOR AND TAB CONTROL HYD	2.22
TUBE, HEATED ELEVATOR Q FEEL PITOT	3.71
CONTROL UNIT, ELEVATOR POWER	3.54
SENSOR, ANGLE-OF-ATTACK	2.22
ELEVATOR INDICATOR AND WARNING–GENERAL	2.97
SWITCH, ELEVATOR FEEL DIFFERENTIAL PRESSURE WARNING	2.22
ACTUATOR, JACK SCREW ASSY MAIN ELEVATOR	2.97
SWITCH, TRAILING EDGE FLAP LIMIT	3.71
VALVE, TRAILING EDGE FLAP CONTROL	11.53
DRUM, TRAILING EDGE POSITION XMTR	1.48
INDICATOR, TRAILING EDGE POSITION	1.48
FLIGHT SPOILER–GENERAL	2.22
ACTUATOR, FLIGHT SPOILER	9.47
LEVER, GROUND SPOILER CONTROL	1.48
SWITCH, SPOILER POSITION AND WARNING GENERAL	2.22
ACTUATOR, LEADING EDGE FLAP CONTROL	1.48
ACTUATOR, LEADING EDGE SLAT CONTROL	13.35
LEADING EDGE FLAP/SLAT POSITION/WARNING–GENERAL	4.45
SWITCH, LEADING EDGE FLAPS POSITION AND WARNING	7.41
OTHER	11.89

ATA 28

FUEL–GENERAL	19.02
FUEL QUANTITY INDICATING–GENERAL	19.02
INDICATOR, FUEL QUANTITY	30.29
OTHER	31.71

ATA 29

HYD POWER–GENERAL	2.28
MAIN HYD SYS (A) (UTILITY)–GEN	6.57
CONNECTOR, MAIN HYD SYS DEPRESSURIZATION VALVE	2.28
FILTER, MAIN HYD SYS	6.57
LINE, MAIN HYD SYS GENERAL	11.12
PUMP, MAIN HYD ENG DRIVEN HYD	25.04
PUMP, MAIN HYD (B) SYS MOTOR DRIVEN	23.64
RESERVOIR, MAIN HYD (B) SYS	6.57
VALVE, MAIN HYD (B) SYS CARTRIDGE	2.28
OTHER	13.65

ATA 30

CONNECTOR, WING THERMAL ANTICE SHUT OFF VALVE	9.63
VALVE, WING AIRFOIL ANTI ICE SHUT OFF	32.60
VALVE, ENG NOSE COWL ANTI ICE GENERAL	9.63
MOTOR, CONTROL WINDOW WIPER	9.63
OTHER	38.51

ATA 32

MODULE, LANDING GEAR ELECTRICAL	9.58
MIG DOOR ACTUATION	3.09
NLG–GENERAL	3.74
BRACE, NLG	2.59
SEAL, NLG SHOCK STRUT	1.30
STRUT, NLG	9.58
NLG DOOR–GENERAL	3.09
NDG GEAR EXTENSION AND RETRACTION–GENERAL	1.30
MLG EXTENSION AND RETRACTION–GENERAL	3.09
NLG EXTENSION AND RETRACTION–GENERAL	1.94
CYLINDER, NLG EXTENSION/RETRACTION XFER	1.94
EXTENSION MECHM, LG MANUAL	1.30
BRAKE, MAIN LANDING GEAR HYD ACTUATOR	5.19
SHIELD, LG WHEEL ANTISKID CONTROL	3.24
SWITCH LG WHEEL ANTI SKID TEST	1.30
WHEEL, MLG (INCLS TIRE)	15.41
NLG WHEEL STEERING–GENERAL	3.74
SEAL, NLG WHEEL STEERING GENERAL	3.09
VALVE, NLG WHEEL STEERING METERING	3.74
LG POSITION AND WARNING GENERAL	7.13
LG POSITION INDICATING AND WARNING GENERAL	3.09
SWITCH, NLG POSITION	3.74
WIRING, LG POSITION INDICATING/WARNING	1.94
OTHER	5.85

ATA 33

XFMR, FLIGHT COCKPIT PANEL LIGHTING GENERAL	6.67
WIRING, STAIRWAY/ENTRY LIGHT GENERAL	6.67
LENS, NAV LIGHT	6.67
BATTERY, EMERGENCY EXIT LIGHT	13.33
CONNR, EMERG EXIT LIGHT	6.67
LIGHT, EMERG EXIT	20.00
RELAY, EMERG EXIT LIGHT	13.33
OTHER	26.66

ATA 34

INDICATOR, PNEU AIR DATA ALTIMETER	4.35
GYRO, REMOTE MAGNETIC COMPASS DIRECTIONAL	6.52
INDICATOR, STANDBY ARTIFICIAL HORIZON	4.35
ANTENNA, WEATHER RADAR	6.52
INDICATOR, WEATHER RADAR	4.35
PANEL, WEATHER RADAR CONT	10.87
TRANSCEIVER, WEATHER RADAR	17.39
WIRING, VHF/VOR/LCL2R COAXIAL	4.35
RECEIVER, ADF	4.35
OTHER	36.95

ATA 35

LINE, FLIGHT COCKPIT OXYGEN DISTRIBUTION	50.00
OTHER	50.00

ATA 36

CONNECTOR, BLEED AIR DISTRIBUTION MECHANICAL GENERAL	5.96
LINE, BLEED AIR DISTRIBUTION	5.96
VALVE, ENG BLEED AIR SHUT OFF	20.87
VALVE, ENG 13TH STAGE PRES MODULATING	17.21
CONNECTOR, ENG BLEED AIR COOLER GENERAL	5.96
DUCT, ENG PYLON CABIN AIR DISTRIBUTION	20.19
DUCT, ENG 6TH STAGE BLEED AIR DISTRIBUTION	8.94
DUCT, ENG 13TH STAGE BLEED AIR DISTRIBUTION	8.94
OTHER	5.97

ATA 38

PUMP, TOILET (INCLS MOTOR/FILTER)	28.57
COMPRESSOR, WATER PRESSURIZATION SYSTEM	42.86
OTHER	28.57

ATA 49

AIRBORNE AUXILIARY POWER–GENERAL	14.28
APU ENG STARTING–GENERAL	14.28
APU BLEED AIR–GENERAL	42.86
OTHER	28.58

ATA 52

ARM, MAIN ENTRY DOOR	7.30
SEAL, CARGO COMPARTMENT	3.65
SNUBBER, GALLEY SERVICE DOOR	5.48
DOOR, HYD FILL STATION	18.26
LOCK, FLIGHT COMPARTMENT INTERIOR DOOR	3.65
AFT LOWER STAIR–GENERAL	3.65
ACTR, AFT LOWER STAIR GENERAL	14.19
CARD, DOOR WARNING SWITCH MODULE	12.78
SENSOR, GALLEY SERVICE DOOR WARNING	5.48
OTHER	25.56

ATA 53

SKIN, FUSELAGE	33.33
PANEL, BLOW OUT	50.00
OTHER	16.67

ATA 56

WINDOW, NBR 1 (ASSY-INCLS HEATER)	50.00
WINDOW, FLIGHT COCKPIT NBR 5	33.33
OTHER	16.67

ATA 57

FAIRING, TRAILING EDGE FLAP TRACK	30.77
STOP, SPOILER	38.46
OTHER	30.77

747 Aircraft Component	% of sum of Total
ATA 21	
MACHINE, AIR CONDITIONING AIR CYCLE	34.73
OTHER	65.27
ATA 23	
TRANSCEIVER, HF	13.49
TUNER, HF COMMUNICATIONS ANTENNA CONTROL UNIT	29.36
OTHER	57.15
ATA 24	
ELECTRICAL POWER–GENERAL	5.72
DRIVE, CONSTANT SPEED (CSD)	19.39
GENERATOR, ELECT POWER SYS AC	11.84
CONTROL UNIT, AC GENERATION CONTROL PHASE	3.90
INDICATOR, AC POWER FREQY	4.73
RELAY, EXTERNAL POWER SENSING	4.45
RELAY, EXTERNAL POWER FAILURE	4.61
WIRING, MULTI-USE ELECTRICAL	5.84
OTHER	39.52
ATA 25	
EMERGENCY EQUIPMENT–GENERAL	9.15
BOTTLE, EMERGENCY ESCAPE RAMP-GAS	9.77
OTHER	80.08
ATA 26	
ENG FIRE DETECTION–GENERAL	9.91
CONNECTOR, ENG FIRE DETECTOR SENSOR	4.05
SENSOR, ENG FIRE DETECTOR DUAL (SHROUD)	5.35
DETECTOR, CARGO COMPARTMENT SMOKE	4.68
WING OVERHEAT DETECTION–GENERAL	5.20
SWITCH, WING OVERHEAT DETECTION	31.91
WIRING, WING OVERHEAT DETECTION	16.79
OTHER	22.11
ATA 27	
FLIGHT CONTROL–GENERAL	2.95
LINE, AILERON	1.09
RUDDER AND TAB–GENERAL	1.20

ACTUATOR, RUDDER RATIO CHANGER	8.49
LINE, RUDDER/TAB CONTROL HYDRAULIC	1.03
CONTROL UNIT, RUDDER RATIO CHANGE	6.54
COMPUTER, ELEVATOR FEEL	2.19
CONTROL UNIT, ELEVATOR POWER	1.85
ACCUMULATOR, STABILIZER TRIM AUX HYD SYSTEM	1.03
CONNECTOR, HORIZONTAL STABILIZER TRIM CONTROL MODULE	1.34
FLIGHT CONTROL TRAILING EDGE FLAP CONTROL	1.44
JACKSCREW, TRAILING EDGE FLAP	3.26
TRANSMISSION, TRAILING EDGE FLAP DRIVE	1.34
INDICATOR, TRAILING EDGE FLAP POSITION	1.68
WIRING, TRAILING EDGE FLAP POSITION INDICATING	1.41
ACTUATOR, GROUND SPOILER	1.78
LEADING EDGE FLAP/SLAT CONTROL	5.35
JACKSCREW, LEADING EDGE FLAP	2.05
TUBE, LEADING EDGE FLAP DRIVE TORQUE	5.85
WIRING, LEADING EDGE FLAP/SLAT CONTROL	1.16
DRIVE UNIT, LEADING EDGE FLAP PNEUMATIC	17.51
OTHER	29.47

ATA 28

ACTUATOR, MAIN FUEL TANK XFER VALVE	3.45
VALVE, MAIN FUEL TANK XFER	3.45
CONTROL UNIT, FUEL VOLUMETRIC SHUT-OFF	3.70
PRES FUELING–GENERAL	15.28
VALVE, PRES FUELING ELECTRICAL OPERATED	5.67
TUBING, ENG FUEL SHUT OFF VALVE TO ENGINE	8.41
VALVE, ENG FUEL FEED SHUT-OFF	8.38
FUEL QUANTITY INDICATING–GENERAL	13.09
OTHER	38.57

ATA 29

HYD POWER–GENERAL	5.66
VALVE, HYD POWER SYS (GENERAL)	2.23
MAIN HYD SYS (A) (UTILITY)–GENERAL	5.53
HOSE, MAIN HYD SYS PRES	3.03
HOSE, MAIN HYD ENG DRIVEN HYD PUMP	2.31
LINE, MAIN HYD SYS	7.26
PUMP, MAIN HYD ENG DRIVEN HYD	19.68
TUBING, MAIN HYD SYS	1.38
TUBING, MAIN HYD SYS PRES	3.21
TUBING, MAIN HYD SYS RETURN	1.60
TUBING, CHECK VALVE	3.16
TUBING, HYD CHECK VALVE	1.87
TUBING, HEAT EXCHANGER TO FILTER MODULE	1.51

VALVE, MAIN HYD SYS ENG DRIVEN HYD SYS SUPPLY	5.78
WIRING, MAIN HYD SYS	5.17
MODULAR UNIT, MAIN HYD SYS PRESSURE	2.95
PNEU OPERATED HYD SYS–GENERAL	4.05
PUMP, AIR DRIVEN HYD (ADHP)	2.49
VALVE, ADHP SHUT OFF & CONTROL MODULE	2.90
DRIVE UNIT, AIR DRIVEN HYD PUMP	2.85
OTHER	15.38

ATA 30

VALVE, NOSE COWL SOLENOID CONTROLLED PRESSURE	14.95
WIRING, ENG NOSE COWL ANTI ICE	35.52
CONTROLLER, WINDOW HEAT	18.69
OTHER	30.84

ATA 32

STRUT, MLG SHOCK	1.32
SEAL, MLG SHOCK STRUT	2.32
STRUT, MLG SHOCK	1.20
ROD, MLG STRUT DOOR-TO-STRUT	1.60
SEAL, NLG SHOCK STRUT	1.83
ACTUATOR, MLG TRUCK	1.32
FITTING, MLG HYD TUBING/HOSE	1.72
HOSE, MLG ACTUATOR HYD PRES	3.40
BRAKE, MLG HYD ACTUATED	3.99
FITTING, LG HYD BRAKE TUBING/HOSE (GENERAL)	1.12
LG WHEEL ANTI SKID–GENERAL	1.83
VALVE, LG ANTISKID NORM/RESERVE CONTROL	1.96
CONTROL UNIT, LG WHEEL ANTISKID	1.60
WHEEL, MLG-INCLS TIRES	35.08
ACTUATOR, NLG WHEEL STEERING RUDDER	1.12
MLG STEERING–GENERAL	2.84
ACTUATOR, MLG STEERING	2.44
POSITION AND WARNING–GENERAL	1.12
LG POSITION INDICATING AND WARNING–GENERAL	1.68
SENSOR, NLG LOCK/POSITION	1.36
SENSOR, MLG LOCK POSITION	1.56
SENSOR, MLG TRUCK TILT POSITION	1.12
TOTAL	26.47

ATA 33

WIRING, NAV LIGHT	20.09
LAMP, ANTI COLLISION LIGHT	9.86
POWER SUPPLY, PASSENGER CABIN LIGHTED EMERGENCY EXITS	10.52

WIRING, EMERGENCY EXIT LIGHT	11.54
OTHER	47.99

ATA 34

PNEUMATIC AIR DATA–GENERAL	3.17
COMPUTER AIR DATA (CADC)	6.11
FLIGHT DIRECTOR–GENERAL	3.17
INDICATOR, ATTITUDE DIRECTOR (HDI, FPDI, F)	8.05
WEATHER RADAR–GENERAL	3.87
ANTENNA, WEATHER RADAR	3.05
TRANSCEIVER, WEATHER RADAR	3.46
NAV SYS (INS) – GENERAL	3.26
CARD, INS NAV/UNIT MODULE	2.85
NAVIGATION UNIT, INS	26.67
OTHER	36.34

ATA 36

VALVE, 8TH STAGE BLEED AIR	7.20
VALVE, ENG 15TH STAGE BLEED AIR	7.42
VALVE, PYLON SHUT-OFF PRESS REGULATION	18.57
EXCHANGER, ENG BLEED AIR HEAT	4.62
DUCT, ENG PYLON CABIN AIR DISTRIBUTION–GENERAL	4.72
DUCT, ENG PYLON COMPRESSOR AIR "Y"	11.69
SEAL, ENG PYLON CABIN AIR DISTRIBUTION	3.60
OTHER	30.26

ATA 49

AIRBORNE AUXILIARY POWER–GENERAL	40.77
APU AIR INLET–GENERAL	17.83
ACTUATOR, APU AIR INLET DOOR	11.47
OTHER	29.93

ATA 52

MAIN ENTRY DOORS–GENERAL	7.97
LEVER, MAIN ENTRY DOOR GUIDE (GUIDE ARM)	6.52
CARGO COMPARTMENT DOOR–GENERAL	22.84
HINGE, MLG DOOR	9.38
OTHER	53.29

ATA 56

WINDOW, NBR 1 (ASSY-INCLS HEATER)	94.86
OTHER	5.14

ATA 57

SKIN, WING TRAILING EDGE (HONEYCOMB PANEL)	29.78
TRAILING EDGE FLAP STRUCTURE–GENERAL	14.31
FLAP, TRAILING EDGE FLAP FORE	12.88
ROD, TRAILING EDGE FLAP AFT FLAP ACTUATING	23.28
OTHER	19.75

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